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ELECTRICAL
INSULATING MATERIALS

ELECTRICAL INSULATING MATERIALS

A COMPLETE TREATISE ON THE PREPARATION,
PROPERTIES, AND CHARACTERISTICS OF THE
MATERIALS USED FOR ELECTRICAL INSULATION
WITH A FULL DESCRIPTION OF THE METHODS
OF TESTING

BY

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PREFACE

IN the earlier days of the electrical industry, the insulation of electrical apparatus and machinery for the voltages then employed was a comparatively simple matter, and the majority of the materials then available, although produced for other purposes, were quite sufficiently good for low tension insulation work. During the last fifteen years, however, transmission and distribution voltages have risen very rapidly, until, at the present time, a 220,000 volt transmission line is an accomplished fact. A corresponding advance in the development and improvement of insulating materials in general, cannot, however, be recorded as a fact, and it is therefore not surprising to find that insulation now constitutes the limiting feature preventing a more widely adopted raising of voltages. It is not uncommon in these days to hear of power systems where the E.H.T. voltages employed have been reduced, due to unexpected trouble with the insulation of some part of the system.

Fifteen and twenty years ago, electrical generating, transforming, and switching plant was designed with magnetic, mechanical, and general appearance considerations primarily in view, and the insulation was forced into the general design as of secondary importance. At the present time, on E.H.T. work, the reverse is the case, and the general dimensions and arrangement of the various individual parts of the plant are virtually settled by insulation considerations.

Insulating materials form the weakest part in the construction of most well-designed electrical plant, and yet it is regrettable how little general information on this important subject is available. In the following pages an endeavour has been made to deal with all the insulating materials employed in modern electrical work, giving as much information as possible with regard to their prime sources and the conditions of their preliminary preparation and manufacture. Some apology may be needed for tracing materials, such as cotton cloth, for instance, right back to the botanical considerations of the

various species of cotton plants from which the valuable fibre is obtained, but the recently recorded advances made in cotton insulated wires would never have been possible had not the botanist been called in. Similarly, mica, asbestos, and similar materials have been dealt with from their sources. When due consideration is given to the innumerable samples of cheap micas submitted to electrical manufacturers and others by firms styling themselves direct representatives of mines in various parts of the world, it is necessary some fundamental information on these products should be available to protect against the purchasing of quite unsuitable materials.

As far as possible, numerical data and figures have been avoided which have not been obtained by the test methods set forth in Appendix I. These test methods are everywhere in accordance with recently published standards of the British Electrical and Allied Industries Research Association. It is fervently to be hoped that these E.R.A. test methods will become the only recognized methods employed in British works and laboratories, since experience has shown that much misunderstanding and disappointment can be brought about by comparisons of results of tests made by methods and using apparatus not in accordance with some common standard. It is due to the complete inconsistency and lack of agreement of the majority of figures generally available that comparatively little numerical data have been included in this work. This fact in itself constitutes a strong plea for the general acceptance of the standardized methods of ascertaining and expressing the properties of materials now being worked out by the British Electrical and Allied Industries Research Association.

Unless otherwise stated, all figures quoted are those which may be expected from tests made to E.R.A. conditions, and the author wishes to express his appreciation of the kindness of the Association, which, through its Director, Mr. E. B. Wedmore, M.I.E.E., F.Inst.P., has given consent to the publication of the information in Appendix I.

A Bibliography is included (in Appendix II) of the publications which have been consulted in the preparation of the MSS. It is not claimed that this bibliography accounts for more than a very small percentage of the works available on

insulating materials, but the list merely indicates those authorities which the author has found useful to him during many years working with insulating materials and insulation problems. In addition, a list has been included, at the conclusion of each chapter, of the products and trade names of materials answering to the descriptions of those dealt with in the text. Again, this list does not pose as being complete, but the author would like to take this opportunity of expressing his appreciation of the kindness of the many firms mentioned for supplying him with details of the products they manufacture. It is to be regretted that a very large percentage of the numerical data which have been supplied so generously has had to be omitted because it has been virtually impossible to co-relate it with figures obtained by standardized methods of test. For instance, in more than one case suppliers of insulating materials have stated that their product "withstands an electric test of — thousand volts," without any reference to time of application, temperature, condition, or thickness. Similarly, in dealing with mechanical characteristics, such terms as "Compression Strength," "Crushing Strength," "Resistance to Crushing," etc., are used without discrimination, so that the figures shown are nearly valueless, even though in some cases they have been produced by recognized testing authorities.

In particular, the author would like to acknowledge the assistance given by the Metropolitan-Vickers Electrical Co., Ltd., of Manchester, for permission to use much of the information supplied in the text throughout the book.

The foregoing acknowledgments would not be complete without reference to the valuable help which has been given by Mr. A. R. Dunton, A.M.I.E.E., and Major A. W. Muir, D.S.O., M.C., B.Sc., in preparing numerical data, correcting proofs, and making all arrangements for publication whilst the author has been resident abroad. For assistance with Chapter I the author's thanks are due to Mr. B. L. Goodlet.

SHATURA, NR. MOSCOW,
RUSSIA.

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ELECTRICAL INSULATING MATERIALS

CHAPTER I

THEORETICAL CONSIDERATIONS

Dielectrics and Conductors.

THE term " Dielectric " is commonly used to denote a medium in which the maintenance of a constant electric field does not involve the continuous supply of an appreciable amount of energy from outside sources. It will be seen that this definition is identical with that of a non-conductor or insulator, and takes no account of the inductive properties of the medium. Some writers therefore define dielectrics as substances which increase the electrostatic induction when introduced into a field, regarding dielectrics as the analogy of the paramagnetic materials of magnetism.

According to this point of view, all substances are both dielectrics and conductors, since no substance known to science has the property of diminishing the electrostatic induction when introduced into a field, and all substances require a continuous supply of energy to maintain a field once established, although the rate of energy supply necessary in some cases may be very small. In order to establish a field of given intensity, a certain amount of energy is required, which energy is stored in the dielectric. In maintaining a field, energy is dissipated through conduction, and if this energy is not supplied from external sources it will be supplied by the energy stored in the dielectric itself. The field in the latter will then decay at a rate depending upon its energy-storing and energy-dissipating properties. An excellent example of such decay is furnished by the loss of charge method of measuring the insulation resistance of a cable or condenser.

The electrical properties of a substance may thus be characterized by an " inductive " or energy-storing constant K , and

a "conductive" or energy dissipating constant γ . K is variously termed the specific inductive capacity, dielectric constant, or permittivity, while γ is termed the conductivity of the substance under consideration.

These quantities are defined by the equations

$$D = \frac{KG}{a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$i_c = \gamma G \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Where G = field strength or voltage gradient in volts per centimetre.

D = electric displacement in coulombs per square centimetre.

i_c = conduction current density amperes per square centimetre.

a = constant of the units employed (equal to $36\pi \times 10^{11}$)

The loss due to conduction in the dielectric will be

$$W = Gi_c = \gamma G^2 \text{ watts per cc.} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Further, by Maxwell's theory, a change of displacement is equivalent to a current in the dielectric. Writing i_d for the displacement current density

$$i_d = \frac{dD}{dt} = \frac{K}{a} \frac{dG}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The relations (1) to (4) are quite general and the field strength G may be any desired function of time. A particular case of special practical importance is when the field strength is expressed by the equation

$$G = G_o \sin \omega t$$

where G_o is the amplitude and ω the circular frequency of the alternating field. In this case i_c and i_d are also alternating quantities

$$i_c = \gamma G_o \sin \omega t$$

$$i_d = \frac{K}{a} G_o \cos \omega t$$

The dielectric thus carries two currents, one the conduction current of amplitude

$$i_c = \gamma G_o$$

the other, the displacement current of amplitude

$$i_d = \frac{\omega K}{a} G_o$$

The conduction current is independent of the frequency and is in phase with the field strength. The displacement current is proportional to the frequency and leads the field by 90° . The relations of the various quantities to each other are shown by the vector diagram, Fig. 1.

By (3), the power loss at any instant is

$$W' = Gi_c = Gi \cos \phi = Gi \sin \delta$$

From Fig. 1,

$$I = \frac{\omega K}{a} \frac{G_o}{\cos \delta}$$

The average power loss is, therefore;

$$W'_{average} = \frac{1}{2} \frac{\omega K}{a} G_o^2 \tan \delta \text{ watts per cc.} \quad (5)$$

The factor $\frac{1}{2}$ is introduced because G_o is the maximum and not the effective value of the field intensity. Equations (5) and (3) will be seen to be identical if the value for $\tan \delta$ is substituted from Fig. 1. In most practical cases only the total loss in the dielectric can be measured. If V_o is the amplitude of the voltage impressed on the dielectric or condenser, and C is the capacity, then this total loss will be

$$W_{average} = \frac{1}{2} \omega C V_o^2 \tan \delta \text{ watts.} \quad (5a)$$

Similarly, if g is the conductance of the condenser,

$$W_{average} = \frac{1}{2} g V_o^2 \text{ watts.} \quad (3a)$$

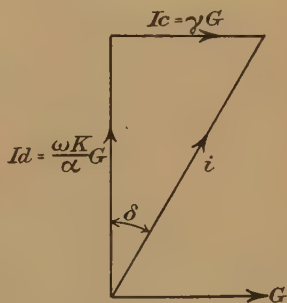


FIG. 1.—Vector Diagram for an Ideal Dielectric.

When the angle δ is small, $\sin \delta$ and $\tan \delta$ are nearly equal. The factor $\sin \delta = \cos \varphi$ is termed the power factor of the dielectric.

It will be seen that, according to equations (3a) and (5a), if an effective alternating voltage V be applied to a condenser, the resulting loss should be the same as should occur if a continuous voltage V were applied to the same condenser. Actually, however, the loss with the alternating voltage is always the greater; moreover the equivalent alternating conductance $\frac{W}{V^2}$ is not constant but varies with frequency, temperature, voltage and many other factors. This and other phenomena, such as residual charge, form the well-known but little explained dielectric anomalies to be mentioned later. It is not possible, therefore, to determine the loss in a dielectric under alternating stress in the same way as the loss in a copper conductor carrying an alternating current, i.e. by measuring the conductance with continuous current and substituting in equation (3a). For practical work, however, equations (3a) and (5a) are assumed to hold true, the deviations being looked after by assuming the quantities g , C , and $\tan \delta$ to be not constants but variables, and expressing them as functions of the different independent variables entering into the problem.

Residual Phenomena.

In the preceding section, the properties of a dielectric were considered to be completely expressed by the coefficients of conductivity and inductivity there defined. When, however, the behaviour of dielectrics is studied in greater detail, certain secondary phenomena appear which are not explainable by the simple theory outlined above. According to this theory, when a condenser with such a dielectric is connected to a source of constant potential, two currents will flow in the circuit, one of which will be permanent—the conduction current flowing through the dielectric—while the other, the charging current, will die away at a rate depending on the resistance, inductance, and capacity of the circuit. However, in practice, it is found that paraffin is almost the only solid dielectric which even partially fulfils these requirements; the

majority of solid and liquid dielectrics behave in a somewhat different manner.

When a condenser is being charged the potential across it does not soon reach that of the supply : long after the normal charging current has died away a current flows into the condenser, usually decreasing with time at a very slow rate, often lasting hours and sometimes days. Similarly on discharge there may be also a current decreasing at a slow rate long after the initial current rush has died down ; such currents are termed " absorption " currents, and the appertaining charge, the " residual " charge of the condenser. It has been found in general that the purer a dielectric is chemically, the smaller are the residual effects. Moreover, all dielectrics do not behave in the same manner ; in some cases the absorption current on discharge is of the same magnitude as that on charging, i.e. the energy involved is returnable, while in other cases, notably where the ionic mobility is high, as in liquids and porous solids, discharge currents of similar magnitude do not occur.

Although these phenomena were observed by Fleming Jenkin, Latimer Clerk, and others more than sixty years ago, there is as yet no generally accepted theory explaining them in a satisfactory manner. The view most widely held is that these anomalies are due to the unhomogeniety of commercial dielectrics, and considerable experimental evidence is available in support of this contention. However, notwithstanding the ingenious theories developed by Maxwell, von Schweidler, and K. W. Wagner on this assumption, the subject yet offers a wide scope for further investigation.

The Electrical Breakdown of Insulation.

In the preceding sections, an outline has been given of the behaviour of a dielectric in an electric field, but nothing has been said of the chemical and physical changes produced in a dielectric by the action of the field. Experience has shown that the potential difference between two electrodes immersed in a dielectric medium cannot be increased without limit. As the potential difference is increased, chemical and physical alterations will occur in the dielectric, which, under certain

conditions, may cause the material to lose its non-conducting properties. An appreciable difference of potential between the electrodes can then no longer be maintained without the expenditure of large amounts of power. When this occurs, the dielectric is said to have broken down and the corresponding potential difference at which this occurs is termed the breakdown voltage. This breakdown may be permanent or temporary, according as to whether the dielectric is solid, liquid, or gaseous. The breakdown of dielectrics is a subject of the greatest complexity, and in spite of the fact that for the last thirty years an ever-increasing number of investigators have been working on the problem, a satisfactory theory of breakdown has yet to be evolved. The breakdown of a dielectric is dependent upon its chemical composition and microstructure, on the temperature and humidity conditions existing at the time of test, on factors such as the geometric form and material of the electrodes, the nature and area of their contact with the dielectric, on the rate and time of application of the electric field, if the field is alternating, on its wave form and frequency, on the thickness of the sample tested, on its previous treatment, electrical and thermal, and on many other factors more or less obscure. With so many known and unknown variables, it will be realized that even a qualitative analysis of the problem can hardly be given with any degree of certainty. While many different theories have been proposed at various times to account for the phenomena accompanying the breakdown of dielectrics, only three of these have gained any considerable support. These theories may be termed respectively the Mechanical, Ionic, and Thermal theories of the breakdown of dielectrics. The essentials of these three theories will now be considered.

THE MECHANICAL THEORY. The mechanical theory of breakdown compares the failure of a dielectric to the mechanical rupture of a solid body under stress. According to this theory, the stressing of the dielectric is the most important factor in producing the breakdown, and every dielectric is supposed to have a certain limiting value of stress which cannot be exceeded without damage to the dielectric. This is termed the "electric strength," and defined as the maximum

value of field intensity which can exist in a dielectric without a disruptive discharge taking place. The precise mechanism of this disruption has never been clearly defined, but is generally assumed to be connected with the mechanical forces set up in the dielectric under the action of the field. For gases, this theory was finally abandoned after it was found that the "electric strength" of a gas, calculated from experimental results, is a function of the radius of curvature of the electrode around which rupture takes place. The experiments on the breakdown of single core cables carried out by K. W. Wagner, in 1905, are generally acknowledged to dispose of the idea of a constant electric strength in the case of solid dielectrics.

THE IONIC THEORY. According to the electron theory, a current is identified with the motion of the elementary charges of electricity; its magnitude will depend upon the field intensity and the number and mobility of the ions present in the field. In dielectrics the number and mobility of the free electrons and ions is low, and the conduction current therefore small. If by any means the number of ions in the dielectric can be increased, a corresponding increase in the current will occur. The ionic theory of breakdown shows that, under certain conditions, a practically unlimited number of ions (and therefore unlimited current) may be formed in the dielectric due to the action of the field itself. The ionic theory, or theory of ionization by collision, was developed by Prof. Townsend to explain the phenomena accompanying the conduction of electricity through gases, and is briefly as follows. If an ion situated in a uniform field were perfectly free to move, it would do so with a constant acceleration. The ion, however, is moving through the molecules of the surrounding medium; its motion is therefore made up of a series of short runs, terminating in collisions in which the kinetic energy acquired by the ion is dissipated. It is not difficult to show that under these circumstances the ion will travel a certain mean free path between collisions and move with a certain average velocity which is proportional to the field. As the field intensity is increased, the velocity and kinetic energy of the moving ions will also increase. When the ions have attained a sufficient velocity in their mean free path, the neutral atoms

and molecules will be disintegrated on collision, and new ions will be produced. These in turn are also acted upon by the field and produce more ions, so that the number of ions in the field increases very rapidly. When a certain field intensity is reached, the number of ions will continue to increase indefinitely and the current will become very large. The dielectric may then be said to have broken down. The ionic theory is generally accepted as explaining the breakdown of gases in a satisfactory manner, but its application to solid and liquid dielectrics up to the present has not been attended by any marked success.

THE THERMAL THEORY. While much attention has recently been focussed on the theory of the breakdown of solid dielectrics outlined in the work of K. W. Wagner and others, the essentials of this theory are to be found in the discussion by Prof. Miles Walker of Dr. Rayner's paper, "High Voltage Tests and Energy Losses in Insulating Materials" (*Journal I.E.E.*, Vol. 49, 1912, p. 3). The main points of Prof. Walker's theory are as follows—

All insulating materials have a very high temperature coefficient of conductivity, and the heating of a dielectric will thus be accompanied by a large increase in its conductivity. When a dielectric is under stress, a conversion of electrical energy to thermal energy will take place in it. The rise in temperature of the dielectric due to this cause will increase its conductivity; more current will flow, producing a further increase of loss, and so on. The temperature of the dielectric will thus continue to rise until either stable conditions are reached or the dielectric is destroyed due to the chemical changes produced by the high temperature attained. Stable conditions will be reached at the temperature at which the rate of heat generation is equal to the rate of heat dissipation, and can only occur if the rate of increase of loss with temperature is less than the rate of increase of heat dissipation with temperature.

For a clearer understanding of what is actually occurring during this process, the highest maintained A.C. stress test suggested by Mr. A. R. Everest gives valuable information.

Fig. 2 shows a typical curve obtained from this test when

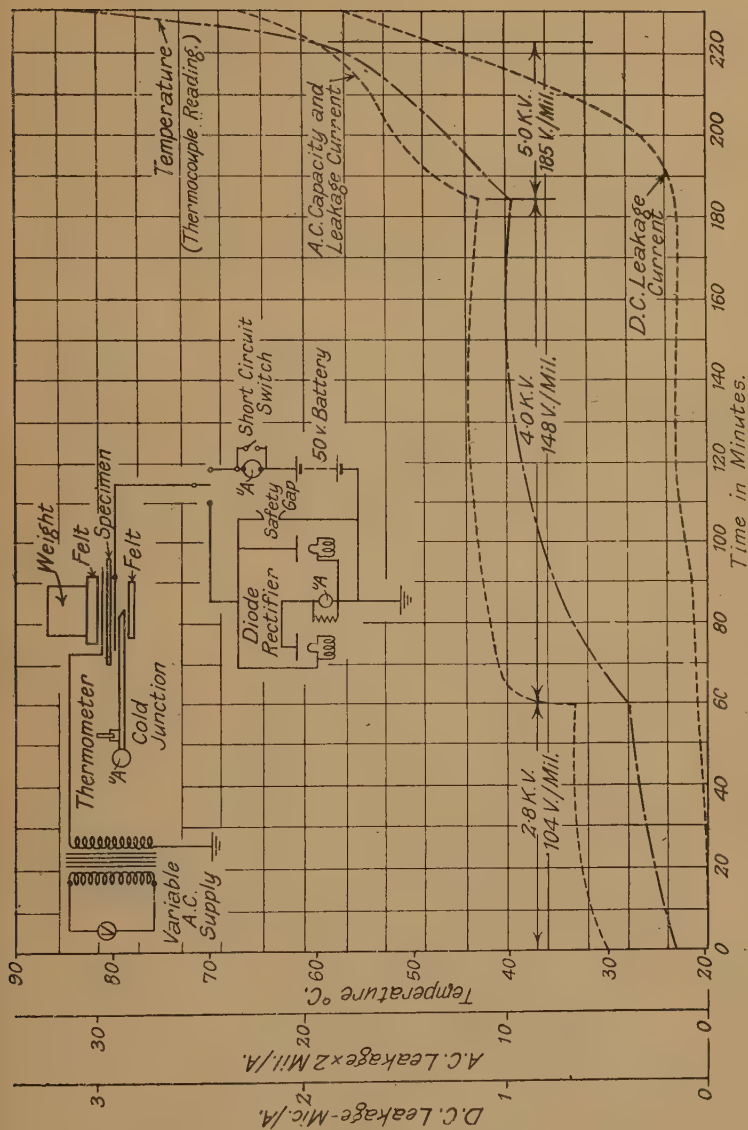


FIG. 2.—Highest Maintained A.C. Stress Test on Varnished Cloth. Specimen conditioned for 30 mins. at 80° C. before testing. Temperature of atmosphere, 18° C.

conducted as prescribed in E.R.A. Report A/S2 (see *I.E.E. Journal*, Vol. 60, July, 1922; pp. 794-802).

In addition to the measurement of temperature of the specimen by thermocouple, and of the A.C. leakage current (made up of its two components, i.e. capacity current and "in phase" leakage current) recommended in the Report, the measurements have also been made on the same sample by momentarily switching over to D.C. supply and measuring the D.C. leakage current. It is to be noted that both the current measurement and the thermocouple temperature indication show the same failure point for the material.

The starting point of the Wagner theory is also the high temperature coefficient of solid dielectrics. The theory is based upon certain assumptions which are, first, that only the conductivity of certain capillary channels or weak spots is variable, the conductivity of the remainder of the dielectric being practically constant, and, second, that the power VI generated in a channel is equal to the heat flowing away from this channel in one second, or

$$VI = \beta \theta^\eta$$

where θ is temperature and β and η are constants.

The analysis based upon these assumptions shows that the voltampere characteristics of such a dielectric have the same general form as those of the well-known pyroelectric conductors, i.e. a maximum voltage point exists beyond which the conductor is unstable on constant voltage. This point Wagner identifies with the breakdown voltage of the dielectric. By means of special electrodes, Wagner obtained the voltampere characteristics of various commercial dielectrics, the shape of which was found to be similar to that predicted by the theory. However, in spite of the many appealing points of the Wagner theory, certain deductions therefrom, such as the direct proportionality between breakdown voltage and thickness and the linear decrease of breakdown voltage with increasing frequency, do not appear to be borne out by experience. A point of great interest in the Wagner theory, which does not appear to have been previously noted, is the remarkable similarity in shape between the voltampere characteristics of

Wagner and the voltampere curves of an ionized gas. When the final portions of the latter, the brush and arc curves, are included, this similarity is especially suggestive.

Surface Breakdown.

The surface breakdown of a material is intimately connected with the breakdown of air. In considering surface breakdown, it is necessary to distinguish carefully between two cases—

(a) When the electric force has no component normal to the surface.

(b) When such normal component exists.

In (a) the surface breakdown voltage for a given test piece is practically independent of the material. The breakdown in general follows the same laws as the breakdown of air, varying with the temperature, pressure and shape of the field. In addition, however, atmospheric moisture plays an important part, the surface breakdown voltage decreasing rapidly with increasing humidity. This suggests a connection between the surface breakdown voltage and the surface resistance, which decreases with humidity in a similar manner. However, experiments on substances whose surface resistance is unaffected by humidity (paraffin wax) have shown that the variation of surface breakdown voltage with humidity still exists, even in that case. The surface breakdown is also affected by the closeness of the contact between the dielectric and the electrodes—if this is not good, corona and ionization of the air occur and the results may be affected.

In the second case, (b), conditions are entirely different from those in (a); owing to the flux being partly in air and partly in the solid dielectric, the permittivity of the latter plays a most important part. The potential distribution along the surface is not usually uniform. This means that a surface discharge will occur before flashover. With increasing voltage, the surface discharge will pass through three stages—the glow, the brush, and the creeping spark. (Flashover sometimes occurs before the last two stages are reached.) The voltage-distance curves of the glow and brush stages are practically linear, but the length of the creeping spark increases as some power of

the voltage—usually between the third and fifth. The three forms of discharge are differently affected by the nature and condition of the surface (rough or smooth, dry or wet), humidity, and other factors. It will be seen that the term, surface-breakdown-strength of a material, is quite indefinite, and, moreover, surface creepage tests carried out on materials often do not take into account the difference between cases (*a*) and (*b*) above. The results obtained are then entirely misleading.

Effect of Moisture.

In the above consideration it has been assumed the dielectric does not contain moisture, but, in actual practice, moisture is exceedingly difficult to eliminate from the majority of dielectrics, and therefore constitutes the most formidable enemy the insulation engineer has to fight against.

Mr. G. L. Addenbrooke and others have frequently shown that moisture particles in any dielectrics in which they are free to move do actually move to that part of the dielectric where the electric stress is most intense, possibly because the permittivity of water is higher than that of any commercial dielectric. It has also been shown that a common result of local overheating of a dielectric is to expel moisture from the hot portions of the material to cooler parts, particularly where the volatile gases and water vapour cannot escape to the air, as is most frequently the case. Thus, in cables, finished windings of machines and other parts, the presence initially of comparatively evenly distributed small quantities of moisture in the dielectric may very soon result in dangerous conditions being reached, due to a redistribution of moisture.

The effect of varying percentages of moisture (as determined by the humidity of the atmosphere in which the tests were made) has been very thoroughly dealt with in a paper before the Institute of Electrical Engineers of Japan, by Mr. Takeo Akahira (published August, 1923). In this paper the general conclusion has been reached that humidity conditions should always be specified in making tests on insulation, and where possible tests should be made to get insulation resistance or leakage current values at three humidities, so that a curve may be obtained showing the leakage current values to be

expected at any given humidity. This particular research has also shown that leakage current slowly decreases with continued application of the voltage. This phenomenon is, of course, frequently observed by those who test insulating materials, and is ascribable to the drying out of the material by the heat produced by the leakage currents where they are insufficient to raise its temperature to the point of breakdown.

Insulation Resistance.

Insulation resistance may be defined as the actual resistance, as measured with direct current between conducting parts which are insulated from each other. It is only of importance in relation to hygroscopic materials. In such materials the major part of the leakage current is due to moisture in the capillaries, and thus the insulation resistance is very largely determined by the relative dryness of the insulation. Measurements of insulation resistance are more generally taken on finished apparatus and installations than on individual raw materials. For installation and erection work, measurements of the insulation (which can conveniently be made with a megger or other form of testing set) afford an excellent indication as to whether or not the insulation is in a sufficiently dry condition to withstand the application of the voltage test.

Volume Resistivity.

Volume resistivity is defined as the resistance between opposite faces of a unit cube of the material in question. Measurements of volume resistivity are most generally applied to non-hygroscopic materials. Methods of test adopted by the E.R.A. for determining volume resistivity are described in Appendix I.

Surface Resistivity.

Surface resistivity may be defined as the resistance between opposite edges of a unit square area of surface. Since this property is frequently dependent on the general condition and humidity of the surface, it can hardly be regarded as a constant of the material. Methods of measuring the surface resistivity as adopted by the E.R.A. are quoted in Appendix I.

CHAPTER II

GENERAL CLASSIFICATION OF INSULATING MATERIALS

AT various times efforts have been made to classify insulating materials in accordance with their animal, vegetable, or mineral origin, or on a consideration of whether they are liquids or solids, and on other similar bases ; but the classification which will be adopted in this work will be in accordance with the general classification agreed upon in principle by the British Engineering Standards Association (B.E.S.A.), the International Electrotechnical Commission (I.E.C.), the Institute of Electrical Engineers of America (A.I.E.E.), the Verband Deutscher Elektrotechniker (V.D.E.), and other national organizations. This classification is based upon considerations of the maximum temperatures which the respective materials are capable of withstanding in service, and is primarily intended by the various authorities named as a basis on which to found their respective temperature rating rules for electrical machinery. Since these rules are of prime importance in considering all insulating materials, and are daily becoming more widely used and recognized, Table I has been reproduced from a paper contributed to the Institution of Electrical Engineers by the author in conjunction with Lt.-Col. K. G. Maxwell, and read on 23rd April, 1925. This table shows the main points of difference in the temperatures considered allowable in electrical machinery by the various leading authorities.

Unfortunately, the B.E.S.A. Rules do not yet sufficiently define the classification in which such materials as filling compounds, rubber, varnishes, oils, etc., fall, so that in the following classification the letters (B.E.S.A.) have been placed against those materials which have been definitely classified. In all other cases the classification must be regarded as the author's suggestions only. In the case of Class B insulation, the B.E.S.A. Rules state that : " If Class A material is used in conjunction in small quantities for structural purposes only,

the combined materials may be considered as Class B, provided the electrical and mechanical properties of the insulated winding are not impaired by the application of the temperature permitted for Class B material. (The word 'impair' is here used in the sense of causing any change which could disqualify the insulating material for continuous service.)" The limits of this provision have unquestionably been too widely interpreted in the past, and consequently definite values for the percentage of Class A backing material permitted have been suggested in the following classification.

Class O Materials.

1. *Untreated fabrics* of all kinds made from organic fibres, as, for instance, cotton, silk, linen, etc. (B.E.S.A.)
2. *Untreated papers* of all kinds made from organic fibres. (B.E.S.A.)
3. *Untreated tapes, binders, and sleeveings* made from organic fibres. (B.E.S.A.)
4. *Untreated pressboards.*
5. *Untreated timbers and cork.*
6. *Artificial cellulose products.*

Class A Materials.

1. *Treated fabrics* made from organic fibres and either oil impregnated or protected with a varnish coating. This includes varnished cloths (Empire Cloth), etc. (B.E.S.A.)
2. *Treated papers*, including varnished papers or those impregnated with oils, bitumens, or waxes. (B.E.S.A.)
3. *Treated cotton and silk covering on wires*, whether varnished, treated, or immersed in insulating oils. (B.E.S.A.)
4. *Pressboard*, when used in oil or varnish treated.
5. *Vulcanized fibre.*
6. *Treated timbers.*
7. *Treated tapes, binding materials, and sleeveings.*
8. *Varnish-paper products* of all kinds, including materials of the laminated-phenol-formaldehyde class.
9. *Enamelled wires* of all kinds.
10. *Micanite products* made with organic bonds and backings,

as set forth under Class B material, but when the percentage by volume of mica falls below 30 per cent.

11. *Asbestos products* when the percentage by volume of asbestos is less than 75 per cent.

12. *Moulded compositions* made with organic fillers or binders or with bitumen.

Class B Materials.

1. *Micanite products* made with organic bonds, etc. (B.E.S.A.), including—

- (a) Hard or segment micanite.
- (b) Hot moulding micanite.
- (c) Cold moulding or flexible micanite.
- (d) Micafolium.
- (e) Mica-silk, mica-cambric, mica on Jap paper, etc., etc.

Providing in every case that the percentage of organic bond (as, for instance, shellac, oil, or resin varnishes), and of paper or fabric backing is not so large as to reduce the percentage of mica *by volume* to less than 30 per cent.

2. *Heat-resisting micanite.*

3. *Asbestos tapes, fabrics, papers, and cords* providing the amount of cotton or other vegetable fibre added for spinning purposes, etc., does not reduce the percentage *by volume* of asbestos to less than 75 per cent.

4. *Slate and Marble.*

5. *Oxide films.*

6. *Moulded compositions* made with non-organic fillers and binding media (excluding bitumen, etc.).

7. *Non-ignitable boards and mouldings.* (E.R.A. definition.)

Class C Materials.

1. *Block mica.* (B.E.S.A.)

2. *Ceramics*, including glass, porcelain, earthenware, and vitreous enamels.

3. *Steatite, Soapstone, etc.*

4. *Moulded compositions* with mica, asbestos, etc., as fillers, and a vitreous binder.

Unclassified.

1. *Insulating oils.*
2. *Bitumens*, including filling compounds, etc.
3. *Rubber*, and rubber products, including gutta-percha and other latex products.
4. *Varnishes.*

CHAPTER III

INSULATING PAPERS

PAPER is one of the oldest manufactured materials of which we have any record, since its production dates back to 150 years B.C., when history shows that the Chinese had discovered the secrets of its manufacture.

In the cable making industry the value of paper as an insulator has been appreciated and made use of for several years, and paper insulated cables in which it is used both with and without oil impregnation are in general use. In the heavy machine side of electrical work, paper has, however, only of late years taken its place as anything other than a spacing or backing material. This more recent development has largely been brought about by the general introduction of varnished paper products on transformer and E.H.T. switch-gear work.

In view of the growing importance of paper insulation, and the probability of future improvements being closely connected with the selection of suitable fibres and the scientific improvement of the processes of beating and "making," the following notes dealing with these matters are of interest.

Fibres Employed.

The various fibres employed for paper making are enumerated in Table II.*

The table also indicates by name the various processes to which the respective fibres are subjected in order to reduce them to pulp suitable for making into paper. These processes are of considerable importance and may briefly be described as follows—

Alkali Boiling Process (for rags, ropes, jute, hemp, linen, etc.).

The majority of pulps produced from rags, hemp, jute, are

* *Classification of Papers.* The classification, names of papers, and suggested standard thickness have been provisionally proposed by the Electrical Research Association. Appropriate limits for the characteristic properties of each class of paper have been inserted in Table II by the author.

TABLE II.—CLASSIFICATION AND CHARACTERISTIC PROPERTIES OF ELECTRICAL INSULATING PAPERS

Classification E.R.A.	Name of Paper.	Suggested Standard Thickness.	Density, Grains, sq. ft.	Process by which Pulp is Prepared.	Average Tensile (longitudinal) lbs./sq. in.	Strength (Transverse) lbs./sq. in.	Bursting Strength (Mullen).	Ageing Test, Bursting Strength after 48 hours at 105° C.	Double Tear, ozs.	Porosity E.R.A. Test.
I . .	Kraft or Sulphate Pulp	2	44.4	Sulphate Wood Pulp	7500	3500	20 30 40 50	20 30 40 50	4 6 8 10	4
		3	67.7							
		4	94.8							
		5	122.0							
II . .	Absorbent Sul- phate Pulp	2	22.2 45.8 71.8	Sulphate or Soda Wood Pulp	7500	3500	20 30 50	20 30 50	4 6 10	4
		3								
		5								
III . .	Sulphite . .	1	22.2 45.8 71.8	Sulphite Wood Pulp	7500	3500	10 15 20	10 15 20	1 3 5	
		2								
		3								
IV . .	Greaseproof	2	55.6 62.7	Hydrated Sulphate, Chemical Wood Pulp	7500	3500	20 25	18 23	3 5	Non-absorbent
		3								
V } VI }	Rag . . .	2	45.2 } 68.7 } 93.2 }	Mainly Cotton Rags Pure Cotton only	3000	2000	10 } 15 } 20 }	10 } 15 } 20 }	2.5 } 3.5 } 4.5 }	
		3								
		4								
VII . .	Pure Manila	3	75.3 122.0 163.1 216.0	Manilla Hemp only	8500	4000	40 60 70 95	40 60 70 95	6 10 14 20	4.5 2.5 1.0 0.5
		5								
		7								
		9								
VIII . .	Condenser Tissue	1	20.0	Cotton Rags	6000	3000	10	10	1.5	2
IX . .	Jap Tissue . .	1	13.5	Paper Mulberry	5000	1000	15	12	2	
X . .	Manilla . . .	3	5000	Chemical Wood Pulp, Hemp, Jute	5000	2000	20 35 50 65	20 35 50 65	5 8 11 16	
		5								
		7								
		9								
XI . .	Rope . . .	3	7000	Chemical Wood Pulp, Hemp, Jute	7000	4000	30 40 50 60	30 40 50 60	6 10 15 20	
		5								
		7								
		9								
. .	Core Disc . .	1		Chemical Wood Pulp	—	—	—	—	—	—

subjected to boiling with one of the following alkaline reagents—

- (1) Lime.
- (2) Lime and sodium carbonate.
- (3) Caustic soda.

In actual fact, (2) and (3) are the same process, since lime in dilute solution acts on sodium carbonate to produce calcium carbonate and caustic soda, which is utilized in disintegrating the rags. The actual process itself consists of placing the rags or other raw material in a large boiler with the requisite amount of alkaline liquid, and raising the whole to a temperature in the neighbourhood of 145°C . at 40 to 50 lb. per sq. in. of pressure, and maintaining in this condition for a number of hours. On being removed from the boiler, the rags are ready for washing and beating.

Wood Pulp.

Wood pulps are necessarily manufactured by processes differing from those in use with rags and similar textile fibres. Generally speaking, one of the following four methods of reducing the fibrous structure of trees to paper-making pulp is employed.

The majority of timbers have been tried at one time or another for paper making, but by far the largest amount of wood pulp paper is produced from coniferous trees, such as pine, fir, and spruce. In electrical work, and for other high-grade uses, certain special papers are employed, utilizing fibres from the paper mulberry and from special fibres which are distinguished by their length and strength.

Mechanical Wood Pulp Process.

Mechanical wood pulp is prepared by grinding logs of wood against the periphery of large sandstone grinding wheels. The trees are first completely denuded of their bark, and are then forced against the grindstones by hydraulic pressure.

The logs are usually placed parallel to the axis of the stone. Water is allowed to flow on to the surface of the stone during grinding, thus carrying away with it the particles of fibre as

they are torn out from the tree. The pulp from the grinders is then sieved and frequently subjected to a further refining process, in which it passes between two millstones, arranged similarly to those of an ordinary flour mill. It will be realized from the above that, in the production of mechanical wood pulp, the process is cold and the pulp is not subjected to any boiling or other treatment to remove natural resins, gums, etc., with the result that papers made from this pulp are generally unsatisfactory for insulation purposes, due to their extremely poor ageing qualities. In electrical work, mechanical wood pulp papers should never be used.

Soda Wood Pulp Process.

In this process the wood is boiled with caustic soda in the manner that has already been described for dealing with rags, except that the process in general is carried out under a higher pressure and with a larger proportion of alkali. The pressure employed varies from 130 to 160 lb. per sq. in., with a corresponding temperature of 180° C.

(1) Sulphate Wood Pulp Process.

In the soda process, the manufacturers go to considerable trouble to recover the liquor as far as possible, but there is a loss which should amount to 8 to 10 per cent, which is unavoidable, even with the most efficient recovery plant. In the sulphate process, this loss is made up by the addition of sodium sulphate in the place of caustic soda. It is necessary to add 12 to 15 per cent of sodium sulphate to replace 8 to 10 per cent of soda. Even with this larger quantity of sulphate, considerable economy is effected, since the price of caustic soda is so much higher than that of sodium sulphate. The principle of the process depends upon the fact that, when the concentrated liquors are burned to ash during the soda recovery, the sodium sulphate reacts with the carbonaceous matter and is thereby reduced to sodium sulphide, whilst the soda in conjunction with organic matter is converted into sodium carbonate. Causticization is then effected, the lime converting the sodium carbonate into caustic soda, although the

sodium sulphide remains unaffected. The operation of boiling is then carried out with a mixture of caustic soda, sodium sulphide, and unchanged sodium sulphate, which latter has no action on the wood. The sulphate process is particularly suited to hard and resinous woods.

11) Sulphite Wood Pulp Process.

The sulphite process is particularly applicable to green and newly-felled timber, and differs from the two chemical processes described above in that it is an acid process and does not depend upon alkalis to effect disintegration. The liquors employed are calcium bi-sulphite, either alone or together with magnesium bi-sulphite ($\text{CaH}_2(\text{SO}_3)_2$) and ($\text{MgH}_2(\text{SO}_3)_2$) containing an excess of sulphurous acid (SO_2). In general practice, for every two parts sulphurous acid contained as bi-sulphite, the liquor contains one part of sulphurous acid in the free state. As in the previous process, there are a number of commercial methods in use for preparing and reclaiming the chemicals employed, but details of these are hardly within the scope of this work.

The actual apparatus employed for the boiling process depends largely upon whether the operation is carried out according to the Mitscherlich system, which utilizes a dilute liquor and continues the cooking process for long periods at a comparatively low temperature in the neighbourhood of 120°C ., or whether it is done by a quick cooking process, using a stronger acid solution and boiling for considerably shorter times at a temperature in the neighbourhood of 150°C .

Generally speaking, the sulphite process yields a higher quantity of pulp than either the soda or sulphate processes, but, from the point of view of electrical engineering, it is worthy of note that a much larger proportion of resin is found in sulphite wood pulp (0.45 per cent to 0.70 per cent) than is characteristic of soda and sulphate pulps (0.05 per cent). On the other hand, it may also be pointed out that the low temperature boiling to which Mitscherlich sulphite pulps are subjected, results in their retaining considerably greater fibre strength than is found in other grades of chemical wood pulp.

For this reason, Mitscherlich pulps are frequently introduced into high quality papers to give added mechanical strength.

It may be pointed out that almost without exception the manufacture of wood pulp is carried out in close proximity to the forests where the timber is grown, with the result that the pulp is exported from these plants in the form of half beaten slabs (known in the trade as "half-stuff") to the paper mills, where it is finally converted into paper. It has been claimed that unless extreme care is taken, a fermentation is liable to occur in wood pulp in this state during transit, so that papers made, for instance, in Great Britain from imported wood pulp, lack the strength which is obtained in papers made in the country of origin from the same pulp. The difficulty which electrical manufacturers find in obtaining extremely strong kraft papers produced in Great Britain tends to support this theory.

✓ **Beating.**

After boiling, the fibrous material is introduced into beaters, where it is mechanically disintegrated under water by an arrangement of fixed and rotating knives. The most usual arrangement is for the water containing the pulp to be circulated between two sets of knives, one of which is stationary on the bottom of the beater, and the other is mounted on a rotating drum. The distance between the knives is set exceedingly fine, and this setting determines the fineness of the resultant pulp. Sharp knives, closely set, produce a pulp in which the fibres are chopped short, and the resultant paper is found to tear very easily. On the other hand, blunt knives tend to drag the individual fibres apart rather than cut them, and result in a longer fibre in the pulp, thus producing a more fibrous paper, which has advantages from certain electrical points of view.

The pulp is frequently passed through more than one beater, finally passing through the refining beater.

It may be interesting to note that these so-called beaters do not actually subject the fibre to a beating action, but disintegrate the material by cutting and tearing. It is possible the name "beater" dates back to the earliest paper-making

times in the East, when hand beating processes were actually employed. Of recent years, a beater in which the fibre is reduced to pulp by actually being beaten under rotating hammers has been introduced by Mr. H. Jackson, and it is reasonable to anticipate that beaters on this principle may play some considerable part in the manufacture of insulation papers in the future, since they are capable of very rapidly producing a heavily hydrated pulp, and, as will be shown later, such pulps produce high density papers of considerably improved electric strength.

Paper Making.

In the production of electrical papers (as distinct from boards) two general types of paper-making machines are in use—

1. Fourdrinier machine.
2. Single-cylinder or Yankee machine.

Fourdrinier Machine.

In the Fourdrinier machine, the pulp is raised by means of a so-called stuff pump from the stuff chest in which it is stored after leaving the beaters, to an elevated mixing chest where it is diluted with water, and not infrequently subjected to steam heating. At this stage the diluted pulp contains from 98 to 99½ per cent water. From the mixing chest the pulp flows over a so-called sand table, where heavy metallic impurities settle out, or are prevented from going forward to the paper-making machine by lateral barriers. From the sand table the pulp passes over a strainer in which the individual fibres are caused to pass longitudinally through fine mesh sieves. As the individual fibres have only a small sectional area in this direction, this strainer is capable of removing practically all impurities, including knotted lumps of fibres, etc., which have not been thoroughly disintegrated. From the strainer, the fibre passes to the breast box of the machine, whence it flows over a lip on to an endless wire mesh band. Whilst on this band, the thin layer of pulp is given a rapid lateral shaking, in order to induce the individual fibres to become intercrossed and not lie

longitudinally, as they would otherwise tend to do, thus considerably reducing the transverse tensile strength of the paper. As the wire mesh proceeds forward, the water is removed from the pulp partially by drainage through the mesh, but principally by vacuum suction boxes over which the mesh passes. After passing the suction boxes, the wire mesh bearing the web of partially formed paper dips down and passes between couch rolls, the top roll of which is covered with a thick specially manufactured felt jacket, and permits the paper to be squeezed between the top and bottom couch rolls to remove further moisture without damage. On the top of the couch roll is a "doctor," consisting of a cross piece of wood covered with felt, which presses tightly against the surface so as to form a channel along which water can be made to flow, removing any dirt or loose material. The paper, on leaving the couch rolls, is sufficiently strong to support its own weight and passes forward on to the first wet felt, which is a continuous web of felt passing between squeezing rollers, where more water is removed from the paper.

The paper then passes on to a second wet felt, on which its reverse side is in contact with the felt so as to ensure that both sides of the paper receive equal treatment. In some machines a third wet felt is also employed. On leaving the wet felt the paper contains approximately 70 to 75 per cent of moisture, which is then removed by passing it forward with a dry felt in zig-zag fashion over cylinders heated by exhaust steam. The dry felts are themselves kept dry by additional felt-drying cylinders. During this part of the process, the paper is also manœuvred so that first one side and then the other is in contact with the drying cylinders. After leaving the drying felt the paper is fully formed and passes over calendering rolls to the reeling plant.

M.-G. Machine.

So-called machine-glazed papers are produced on a machine similar in principle to the Fourdrinier machine as far as the wet felts, but in which the paper, after leaving the wet felts, does not pass in a zig-zag fashion between hot rollers, but is led over a large diameter heated drum, with one side of the

paper in contact with the drum throughout the whole drying stage. The result is that the paper has a highly glossed finish on the side which has been in contact with the drum, and is rough and unglazed on the reverse side. Such machines are known as single-cylinder or Yankee machines.

Sizing.

Although as a general rule it is not desirable to introduce foreign matters, such as sizing and loading, into papers for use as electrical insulation, it is interesting to note that a great majority of papers offered for such work contain a considerable percentage of sizing materials. Sizing materials are generally introduced into the mixing chest, although certain papers are subject to sizing processes after making. The sizing materials generally employed include rosin, casein, gelatine, starches, etc.

Papers Used in the Electrical Industry as Insulation.

At one time or another a very large number of different classes of paper have been incorporated in the construction of electrical plant and apparatus, and therefore it is exceedingly difficult to reach any hard and fast rule regarding the specific uses of various kinds of papers. In the following notes the general classification of uses suggested by the British Electrical and Allied Industries Research Association has been adopted as representative of British practice.

KRAFT OR SULPHATE PULP PAPERS. (E.R.A. Class I in suggested standard thicknesses 2, 3, 4, and 5 mils.)

Kraft papers are largely employed for the manufacture of varnished paper products and the thinner varieties are used as backing for mica-*folium* and in the production of insulating wraps. As far as British practice is concerned, the papers used are very largely of Swedish origin and produced from sulphate pulp. Sulphite krafts and krafts produced from Mitscherlich pulp are also procurable. The kraft papers used in electrical work should be as far as possible unsized and not machine glazed. The average properties of good quality kraft papers are shown in Table II.

Kraft papers for electrical work should not be coloured, but should be supplied in their natural colour. It may here be stated that in general it is undesirable to add foreign colouring matter or to bleach by chemical means any papers which are to be utilized for insulating purposes.

M.-G. (SULPHITE) PAPERS. (E.R.A. Class III in suggested standard thicknesses 1, 2, and 3 mils.)

These papers are made from sulphite wood pulp, and are produced on the M.-G. paper-making machine. In the author's opinion, M.-G sulphite papers cannot be looked upon as satisfactory materials for electrical work, chiefly on account of their high acidity.

M.-G. sulphite papers are frequently used as backing for micanite and micafolium, and as covering for micanite.

GREASEPROOF PAPERS. (E.R.A. Class IV in suggested standard thicknesses 2 and 3 mils.)

Greaseproof papers are, as a general rule, produced in two ways, one of which is to treat cotton or wood pulp papers with either acid or caustic soda solutions, thus producing a parchmentized surface. Greaseproof and parchments manufactured in this manner should never be used in electrical work.

The E.R.A. have specified that greaseproof papers falling under their classification as Class IV papers shall be made from hydrated chemical wood pulp.

It has long been known that by carrying out the heating process with any fibre for a prolonged period, the pulp reaches a stage in which it is heavily hydrated and becomes slightly sticky or "greasy." Paper made from such pulp has a high density, and consequently a high electric strength, and has all the usual properties attributed to a greaseproof paper.

~Papers made in this manner are used in the manufacture of high grade varnished paper products, and also in the production of insulating wraps.

RAG PULP PAPERS. (E.R.A. Class V in suggested standard thicknesses 2, 3, and 4 mils.)

As their name implies, the rag pulp papers are produced mainly from cotton rags, and possess the advantage that they do not age as readily as papers made from other forms of cellulose, all of which are less pure than cotton.

Rag pulp papers are used as insulation between layers of windings, and also in the manufacture of certain special grades of varnished paper products.

PURE MANILLA PAPER. (E.R.A. Class VII in suggested standard thickness 3, 5, 7, and 9 mils.)

Papers made from pure manilla hemp fibre have been used for many years in the production of paper insulated cables. Such papers are extremely strong, and, as experience has shown, lend themselves to this work. In the production of electrical plant and apparatus, pure manilla papers have been very little used, except in the production of certain special grades of bakelite paper products, where extreme tensile strength has been required.

CONDENSER TISSUE PAPER. (E.R.A. Class VIII in suggested standard thicknesses 0.5, 0.75, and 1 mil.)

Condenser tissue paper is a specialized product only produced by three or four manufacturers for the manufacture of electrical con-

densers. Selected cotton rags are employed, and the greatest care is taken to ensure absolute homogeneity. Condenser tissues are probably the highest grade papers used in the electrical industry.

The pulp for the best makes of condenser tissues is grass bleached, thus avoiding any electrical troubles which might otherwise result from chemical methods of bleaching.

JAPANESE TISSUE PAPER. (E.R.A. Class IX in suggested standard thickness 0.5, 0.75, and 1 mil.)

The majority of Japanese tissue papers used in the electrical industry are produced from the fibre of the paper mulberry (*Broussonetia papyrifera*), although other special tissues employing bamboo, mitsumata, and other fibres are available.

Japanese tissues, as will be seen from Table II, are characterized by high tensile strength in the longitudinal direction, but possess comparatively little strength when tested transversally. They are utilized extensively as backing in the production of mica products.

It should be noted here that there are a considerable number of imitation Japanese tissues on the market, produced from bleached sulphite pulp and from cotton rags.

MANILLA PAPERS. (E.R.A. Class X in suggested standard thicknesses 3, 5, 7, and 9 mils.)

So-called manilla papers, unless definitely specified as pure manilla, are in general produced from chemical wood pulp, jute, and other fibres in conjunction with a greater or less amount of genuine manilla fibre. Not infrequently "manillas" contain no manilla hemp fibres whatsoever. Such papers are used as slot insulation for wrapping core bolts, insulated bobbin flanges, and in other places where stout papers are required to give mechanical rigidity without necessarily high insulation strength.

ROPE PAPERS. (E.R.A. Class XI in suggested standard thicknesses 3, 5, 7, and 9 mils.)

Rope papers are virtually similar in constituents and in use to manilla papers (Class X), described above.

According to usage in the electrical industry, rope papers are most generally red in colour, although there is no reason for this practice.

CORE DISC PAPERS.

Core disc papers are obtainable in thicknesses of 1 mil and upwards, and are in general produced from sulphite pulp on the M.-G. machine. They may be fairly regarded as insulating papers, since their primary function is to eliminate eddy currents in the laminated core of electrical machines.

Core disc papers are frequently coloured in order that they may be used for differentiating the various grades of electrical sheet steels on to which they are pasted.

ASBESTOS PAPERS.

Asbestos papers will be referred to at greater length in Chapter XVII.

Table III, however, shows some characteristic properties of papers produced from asbestos.

It may be emphasized, however, that a very considerable improvement would be obtainable in the mechanical properties of these products if a percentage of strong vegetable fibre were permissible; and it is anticipated that improvements in this direction may follow as soon as the allowable percentage of combustible matter in asbestos insulating products has been fixed by the E.R.A. or other similar body.

TABLE III
PROPERTIES OF ASBESTOS PAPER

Tests.	Thickness in inches.				
	·007.	·010.	·015.	·020.	·025.
Tensile strength in lbs./1 in. width	3	4	4.75	6	8
Bursting strength (Ashcroft lbs./sq. in.)	7	10	12	15	20
Dielectric strength—					
Volts/mil at 20° C.	150	125	100	75	50
80° C.	190	160	125	95	65
180° C.	180	150	120	90	60
Density	.75	.7	.62	.57	.54
Tearing strength (double tear, ozs.)	3.5	5.0	7.0	10	12.0
Longitudinal Resistivity					
megohms. Dry	50,000	50,000	50,000	50,000	50,000
„ Normal	50,000	50,000	50,000	50,000	50,000
„ Damp	25,000	25,000	25,000	25,000	25,000
Transverse Resistivity					
megohms Dry	50,000	50,000	50,000	50,000	50,000
„ Normal	28,000	28,000	28,000	28,000	28,000
„ Damp	11,000	11,000	11,000	11,000	11,000
Included matter soluble in boiling water	From 3% to 4%.				
Weight loss on Ignition	From 15% to 30%.				
Estimated Carbon Content	From 6% to 11%.				
Moisture Absorption after drying at 110° C. and submission to 75% humidity for 1 day	From 1% to 2.5%.				
Moisture loss on drying for 110 hours	From 1.3 to 3.7				
Conducting particles per sq. ft.	From 0 to 16.				
Porosity (ccs air in 15 secs)	From 30 to 50 ccs.				
Percentage decrease in bursting strength after baking at 180° C. for 24 hours	From 20% to 30%.				

Electric Strength of Papers.

Fig. 3 shows the electric strength figures which may be anticipated with good quality papers free from "loading" matter. The curves are shown for tests at 90° C. in oil, and

it will be noted from these results, and those shown in Fig. 4, that at this temperature there exists a marked difference between the values obtained with cotton rag papers and those

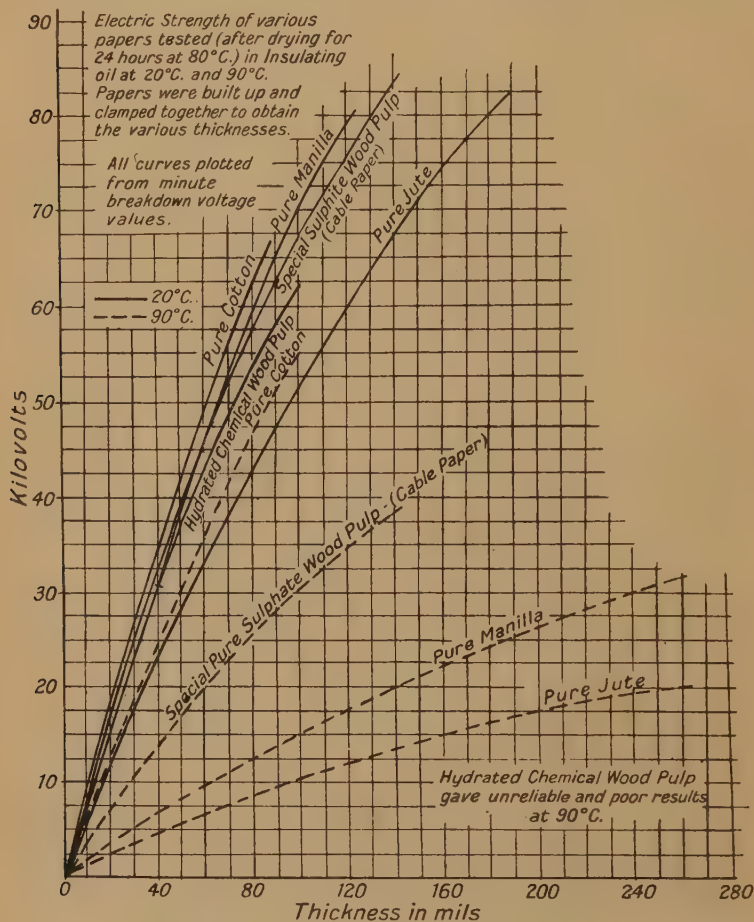


FIG. 3.—Electric Strength of Electrical Insulating Papers at 20° C. and 90° C.

made from more highly lignified fibres. At lower temperatures of about 15° C. to 25° C. this difference is not observable, and in a recent paper published in the *Journal Inst. of Elec. Eng. of Japan*, No. 421, Aug., 1923, by Takeo Akahira, the opinion

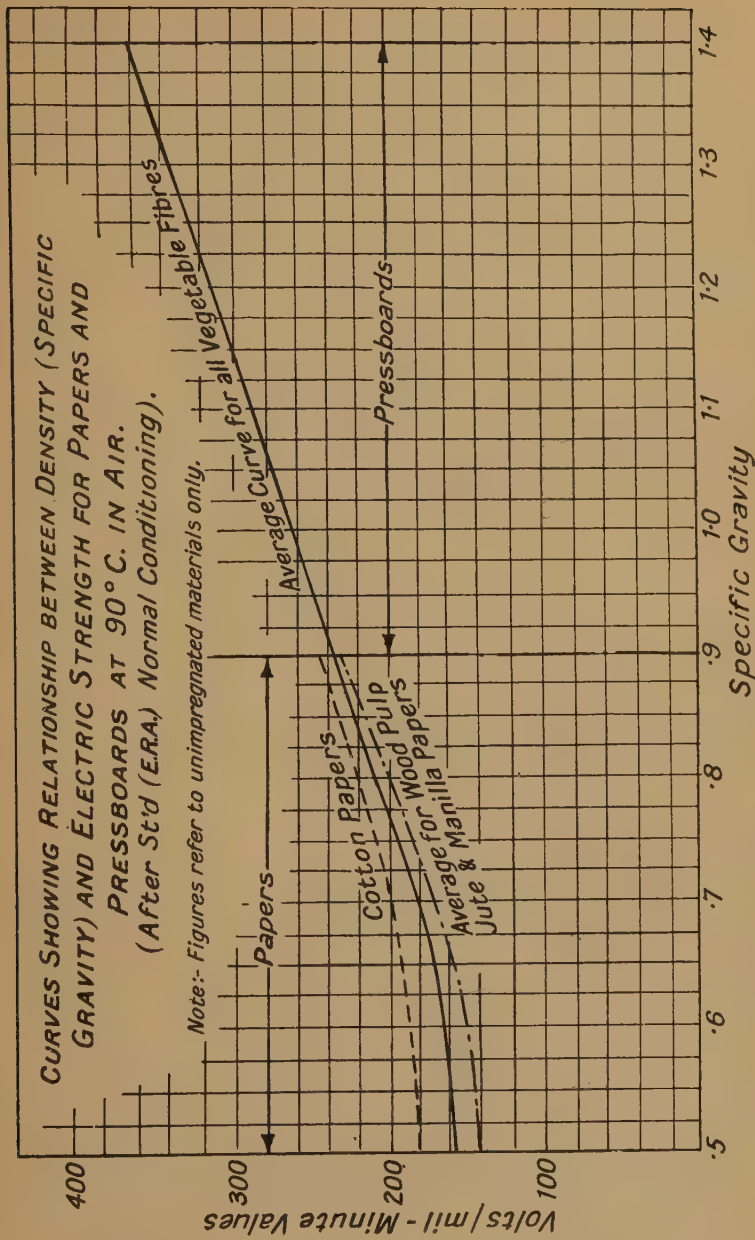


FIG. 4.—Showing Relationship between Density and Electric Strength for Papers and Pressboards.

is recorded that, where resinous matter has been excluded, papers made from different vegetable fibres do not vary in electric strength between very wide limits.

In Fig. 4 the effect of density of the papers on electric strength is clearly shown, and figures for thick papers and pressboards have been included, showing a striking agreement of results between papers and pressboards. These figures are the averages from some hundreds of tests. The increasing of density is thus one of the most important factors in producing insulating papers with high electric strength. This increase must be one which is brought about by reducing the fibres themselves to very fine (almost colloidal) pulp—and not by the addition of loading materials. Numerous ways exist of accomplishing this complete hydration of pulp, but those best known are (1) prolonged beating in an ordinary Hollander; (2) beating in vacuo; (3) beating in a Jackson beater; and (4) passing the pulp through a Plausen mill.

At temperatures of 90° C. to 120° C. the highly lignified fibres show up very poorly in comparison with cotton, which is the purest known form of natural cellulose. Cotton will satisfactorily withstand temperatures of 120° C. without seriously deteriorating. The figure given by Dr. Rayner in "Report on Temperature Experiments carried out at the N.P.L." (see *I.E.E. Journal*, 1905, p. 657) was 125° C.

Moisture in Paper.

During manufacture, paper has moisture driven from it by processes already described, and even should such paper be completely dried, so that no included moisture remains in the sample, it will very soon regain moisture from the atmosphere. Wherever paper is used for electrical purposes it is necessary to bear in mind that, under the generally prevailing conditions of climate in Great Britain, the percentage moisture in the paper varies between 5 per cent and 10 per cent, and it is therefore necessary to dry out papers very carefully before incorporating them in manufactured electrical goods. Moreover, care should be taken to ensure that paper is not allowed to absorb moisture from the air between drying out and impregnating or varnishing.

Treated Papers.

Although practically all paper is treated in some way or another by electrical manufacturers before it forms part of the finished product in which it is included, it is necessary to make some reference to specially treated papers which are sold as such by insulating material manufacturers.

The majority of such papers are those utilized for the manufacture of tubes and cylinders, and in this case great care has to be taken to ensure that the varnishes employed for treatment are suitable and have been applied uniformly in the correct proportions. This question is dealt with at greater length in Chapter IX. Papers treated with linseed oil, varnish, and similar drying-oil varnishes are made and supplied by makers of varnished cloths, and, cut into tape form, are quite largely used as insulation for conductors. Some properties of varnished paper tapes of this kind are shown in Table VI.

Standard Specifications.

Up to date there are no standard specifications for electrical insulating papers issued by the B.E.S.A., but preliminary information which will no doubt ultimately result in a standard specification has been published in the *I.E.E. Journal*, Vol. 61, No. 322, Sept., 1923, page 983, "Directions for the Study of Electrical Insulating Papers (unvarnished) for Purposes other than the Manufacture of Cables." (Ref. A/S5.)

CHAPTER IV

FABRICS, WOVEN TAPES, AND BINDING MATERIALS

ALTHOUGH organic yarns, fabrics, and tapes, especially those from cotton and silk, are of the utmost importance in electrical insulation, it is astonishing how little attention they appear to have had devoted to them as insulators until quite recently. The majority of engineers are content to look upon these products as separators or reinforcement for varnishes and gums rather than as actual insulators. It is true that cotton and silk have not the electric strength obtained with certain high quality varnish films of equal thickness, but recent research has shown that, in the case of cotton at least, the insulating value can be greatly increased at very little expense. Moreover, it has also been shown that a product in which the cotton is used as a reinforcement for insulating varnish coating is appreciably improved from an insulation point of view by ensuring that the cotton itself has been treated to improve its insulating properties. The cotton fibre is naturally coated with a waxy covering containing various chemical impurities—one of which has a very great affinity for water—and since the majority of cotton used until recently in the electrical industry reaches the finished insulated product exactly as it leaves the cotton plant, without any washing whatsoever, these impurities enter into the insulating material. The result is almost as serious as might be anticipated if a constructional engineer employed iron rods coated with a jelly containing a high percentage of sulphuric acid in building reinforced concrete. There is evidence that the British Cotton Industries Research Association has placed in the hands of British manufacturers the secrets of treating cotton to improve its insulation characteristics in this respect, and already electrical engineers and wire coverers are availing themselves of this important discovery.

RAW MATERIALS

The fibres available as electrical insulators are—

1. *Organic fibres.* Cotton, linen, silk, artificial silks.
2. *Inorganic fibres.* Asbestos, glass.

Cotton.

Cotton is the seed hair from several species of the genus *Gossypium*—plants of the mallow family. The fibre is hollow, and when growing is a single straight cylindrical cell, but on ripening the tube flattens and becomes contorted and twisted. The presence of these twists in the fibre makes it possible to spin it. Similar seed hair fibres to those found in the varieties of cotton used, but having no natural small twists in the fibre itself, are common, but cannot be spun economically. The number of twists in a mature cotton fibre varies from 150 to 400 per inch—the longer staple fibres having the highest number of twists per inch. The diameters of the fibres vary from 0.63 to 0.84 mil, the long staple Sea Island and Egyptian yarns having smallest diameters.

The actual number of plants from which commercial cotton is obtained is probably only seven, although *Index Kewensis* lists 42 species and mentions 88 others.

The seven species are—

- | | |
|----------------------------------|---|
| 1. <i>Gossypium arboreum</i> | . Ceylon and Arabia |
| 2. <i>Gossypium herbaceum</i> | . Indian cottons |
| 3. <i>Gossypium hirsutum</i> | . U.S.A. Southern States cotton |
| 4. <i>Gossypium barbadense</i> | . Sea Island and West Egyptian
and some Peruvian cottons |
| 5. <i>Gossypium Peruvianum</i> | . Native Peruvian cottons and
Brazilian cottons |
| 6. <i>Gossypium Sandwichense</i> | . Sandwich Island cotton |
| 7. <i>Gossypium tahitense</i> | . Pacific Island cotton |

The classes of cotton commercially obtainable in Great Britain are shown on page 36.

The raw cotton, after picking, goes through the processes of "ginning," or removing seed pods ("hulls") and other extraneous matter, after which it is pressed into bales and sent to the spinners.

In the spinning mill the fibre is passed through special machinery for "opening" and "beating," so that the individual fibres are separated from the matted condition they were in in the bale, and are left free for passing through the processes of scrutching, carding, and combing to clean them, eliminate short fibres, and lay the good fibres straight, ready for spinning. The fibre, when leaving the carding engine, is formed into a "sliver" (or soft rope-like form) ready for

TABLE IV
CLASSES OF COTTON OBTAINABLE IN GREAT BRITAIN

Class.	Commercial Name.	Spins up to : Counts. ¹	Quality.	Colour.	Staple (inch.)
1	Sea Island .	300	Regular and fine .	Cream .	$1\frac{3}{4}$
2	Meade .	120	Regular and fine .	Cream .	$1\frac{3}{4}$
3	Egyptian—				
	Joanovitch .	150	Fine	Ivory .	$1\frac{1}{2}$
	Sakellarides .	150	Fine and soft .	Ivory .	$1\frac{1}{2}$
	Nubari .	100	Fine, variable, and rather harsher than above	Light brown	$1\frac{3}{8}$
	Abassi .	100	Fine	White .	$1\frac{3}{8}$
	Mita fifi .	100	Moderate and regular	Dark brown	$1\frac{3}{8}$
	Upper .	60	Poorer and liable to be dirty	Dirty brown	$1\frac{1}{8}$
4	Brazilian—				
	Ceara, etc. .	60	Hard and dirty .	Dirty white	1
	Pernams, etc.	60	Hard and dirty .	Dirty white	$1\frac{1}{8}$
5	Peruvian—				
	Sea Island .	100	Soft and good grade	Varies .	$1\frac{3}{8}$
	Smooth .	60	Soft and good grade	White .	$1\frac{1}{8}$
	Rough and mod. rough		Used chiefly for making shoddy, etc. .		$1\frac{1}{4}$
6	American—				
	Orleans .	60	Good grade, soft and strong	White .	$1\frac{1}{8}$
	Uplands .	50	Good grade and soft	White .	1
	Texas .	50	Good grade and soft	White .	1
	Mobile .	50	Moderate	White .	$\frac{7}{8}$
7	Indian—				
	Tinnevelly .	20	Good grade, strong (can be spun in mixture with American)	Light brown	$\frac{7}{8}$
	Sunttee				
	Broach .	20	Good grade, strong .	White .	$\frac{7}{8}$
	Madras,				
	Western .	20	Moderate	Light brown	$\frac{3}{4}$
	Scinde .	10	Inferior quality .	Dirty white	$\frac{5}{8}$
	Bengal .	10	Hard and dirty .	Light brown	$\frac{5}{8}$
8	West African .		This cotton is being developed and is similar to American Uplands		
9	Smyrna .	20·5	The quality of this and other Turkish cottons is liable to vary on account of the tendency to grow native varieties		$\frac{7}{8}$
10	China .	12	Although extensively grown and mostly used in China, in general it is a good grade white cotton and short staple .		$\frac{3}{4}$

¹ The "count" of cotton yarn is the number of hanks of yarn of 840 yd. each, which are necessary to produce 1 lb. weight of the yarn.

passing to the "drawing" frame, where six or more slivers are united and drawn out. The same process is continued on the slubbing, intermediate and roving frames. In each case a little twist is given to the yarn and it leaves the roving frame in a soft strand about $\frac{1}{8}$ in. diameter, ready for the spinning processes.

In spinning, a number of strands from the roving frame are united, given a slight draw, and then twisted into a hard yarn. This process is carried out either on "ring spinning frames," which usually deliver the yarn on bobbins, or on "mules," which deliver the yarn in the form of "cops."

In the operation of weaving, the warp threads are placed in the loom on a "beam," and the thread that is to form the weft is wound into a cop, which is placed inside a shuttle. The warp threads are led from the beam through the healds to a roller at the front of the loom to which they are fastened. When the loom is set in motion, alternate threads (in the case of a plain weave) are pulled up and down respectively by the healds in such a way that the shuttle with its weft thread can be shot by the "picker" through the space between the upper and lower threads of the warp. A comb-like structure, called the "reed," then pushes the weft thread which the shuttle has left behind hard up against the point where the weft threads separate up and down. The healds then reverse their position, so that the weft thread is gripped between the two lots of warp threads and the warp is ready for the shuttle to be shot through again.

In weaving, the warp threads are subjected to considerable friction, which is liable to chafe the yarn and cause breakage, and for this reason the warp yarn is almost invariably sized before being put on to the loom. The sizing materials used include—

(a) AGGLUTINANTS, such as wheat flour, farina starch, sago, rice flour, tapioca, dextrin, Irish moss, gum tragacanth, and gum tragasol, all of which are added to bind the yarn together and render them less liable to be frayed during weaving.

(b) SOFTENING MATERIALS, including vegetable and animal fats and oils, glycerine, glucose, and salts such as magnesium and calcium chlorides which take up moisture from the

atmosphere. These materials are added to soften the yarn to get close and good weaving.

(c) ANTISEPTICS, such as zinc chloride, phenol, zinc sulphate, salicylic acid, thymol, and formaldehyde in case of, or to prevent, mildew appearing due to the starches used.

Sizing materials, it will be seen, are included into fabrics to assist in the weaving process, and since such chemicals and compounds are not desirable in insulating fabrics, it is necessary that fabrics for insulating purposes should be "scoured," to remove all traces of the sizing used in weaving.

All textile yarns are produced as single yarns, but not infrequently two or more yarns are twisted together, thus forming what is known as a "double" yarn. Such yarns are used for the manufacture of duckcloth, webbings, and other textile products, which, however, are not used in electrical work.

Linen.

Linen is a vegetable fibre obtained from the flax plant *Linum usitatissimum*. The fibres themselves are constituted from small cells, consisting of practically pure unligified cellulose. Their average length is approximately 18 in., but variations between 12 in. and 34 in. are commonly met. The mean diameter of the fibre is approximately 6 mils (varies between 1.8 and 25 mils). The fibre is separated from the woody tissue of the plant by a process of decomposition in stagnant water. Linen is a better conductor of heat than cotton, but contains approximately the same amount of hygroscopic moisture (approximately 8.5 per cent.)

The following sources of flax are generally recognized—

RUSSIA. In 1913 over 90 per cent of the world's supply of flax was grown in the Russian Empire. Russian flaxes are known as Slanetz (dew-retted), Motchenetz (water-retted), and Siretz (ungraded fibre). The three kinds of flax are exported from Russia in no less than 32 varieties.

HOLLAND. Dutch flax is exported in six grades.

BELGIUM. *Flemish flax* (blue flax) includes Bruges, Thisselt, Ghent, Lokeren, and St. Nicholas, and is graded in seven grades.

Courtrai flax is also graded into seven grades.

Furnes and Bergues flax is graded A, B, C, and D.

Walloon flax is graded II, III, and IV.

Zealand flax is graded IX, VIII, VII, VI.

Friesland flax is graded in ten grades.

FRANCE. French flax is known by districts in which it is grown, and includes Wavrin, Fluies, Douai, Hazebrouck, Picardy, and Harnes.

IRELAND. Irish flax is known by the names of the counties in which it is grown.

CANADA. Canadian flax is in no definite grades.

Austria, Hungary, Bulgaria, Italy, and the Netherlands also produce flax in smaller quantities.

(Attempts, attended with a certain degree of success, are being made to grow flax in Egypt, Bihar (India), Transvaal, Orange River Colony, and various Australian districts.)

The linen fibre is separated from the stem of the flax plant by processes known as "rippling," which is a mechanical process of removing leaves, seed heads, etc., and "retting," which consists of leaving the flax plant stems to decompose in water, so that cellulose is easily separated by the subsequent processes of "beating" to break up woody matter, and scrutching, which leaves the fibres clean and ready for spinning.

Linen yarn is either "dry spun," which produces coarse yarns of 5 to 30 counts, or "wet spun," which produces much higher counts, from 30 to 80. (*Note*.—The count in linen yarn in Great Britain is the number of leas of 300 yd. each, which are necessary to produce 1 lb. weight of yarn. Linen count is convertible to cotton count by multiplying by 2.8.)

Silk.

Silk is an animal fibre consisting of a continuous thread which is spun by the silkworm. This thread may be as long as 1,300 yd. (2,000 yd. for wild silks), and has a diameter varying from 0.5 mil to 1.0 mil (average, 0.83 mil). The fibre is not cellular, but in its natural state consists of two continuous homogeneous filaments of fibroin cemented together with a secretion called sericin. In silk in its manufactured state this cement is often partially removed (degumming).

Silk is an extremely hygroscopic material, and under favourable conditions may absorb 30 per cent of its weight of moisture and still appear dry. In its normal commercially "conditioned" state, silk contains 9.91 per cent moisture ("regain" 11 per cent) and is, therefore, some 40 per cent more hygroscopic than cotton.

The following table shows the chief varieties of silk—

Bombyx mori	Japan
	Italy
	China
Bombyx fortunaticus	Bengal
Bombyx textor	India
Antheraea mylitta	India
Attacus ricini	India
	America
Attacus cynthia	India
Attacus silene	India
Attacus atlas	India
Antheraea yamamai	Japan
Cricula tristrata	India
Antheraea peruyi	China

The filaments from the cocoon are worked up and put on the market either as—

(a) **RAW SILK**, which is produced by unwinding (reeling) the cocoon and merely twisting together two or more of the resulting filaments without further treatment. Raw silk may be *Organzine* silk, from the best selected cocoons, or *Tram* silk, from the poorer cocoons. The former is largely used for warps and the latter for weft (filling). Tram silk is frequently degummed.

(b) **FLOSS SILK**, which is produced from the filaments taken from broken or immature cocoons or has otherwise become damaged. In this case the broken lengths of filaments are degummed and then carded and spun by special machinery (in much the same way as are vegetable fibres) to produce spun silk.

There are many systems of expressing the size of threads in the silk industry but all systems differentiate between raw silk and spun silk.

RAW SILK: INTERNATIONAL TITRE. The fineness of raw silk thread is expressed according to the International Standard as the number of deniers (0.0531 gramme) a skein of 500

metres length will weigh. This number is frequently referred to as the "international titre," and may be converted to the titres of other nations—

To Turin titre by multiplying by	.	.	.	0.8931
„ Milan „ „ „ „	.	.	.	0.9315
„ French „ „ „ „	.	.	.	0.8964
„ Italian (legal) and Swiss titres	.	.	.	0.9000

The size of spun silk yarn is almost invariably expressed in the same terms as that used for cotton yarn—i.e. the count is the number of hanks of 840 yd. each which go to constitute 1 lb. weight of the material.

Artificial Silks.

The details of manufacture of this material are separately dealt with in Chapter XVI.

Asbestos.

The sources and methods of preparing and utilizing asbestos fibres are dealt with in Chapter XVII.

Glass.

In his work on *Textile Fibres*, Matthews gives some short account of the use of spun glass as a textile fibre. The art of producing fine glass filaments is well understood, and it is reasonable to anticipate that the future may see the development of special flexible glasses which may be drawn into fibres flexible enough to use as insulation on wires or in producing glass woven tapes.

UNTREATED FABRICS AND TAPES

Cambrics, Calico, Etc.

Sea Island cotton, it will be seen from Table IV, is much the finest variety, and is capable of being spun to extremely fine counts. With the finest yarn of 180 to 200 counts, it is possible to produce a fabric less than 2 mils in thickness. Such a material might be utilized as an alternative to silk in the manufacture of fabric mica tapes. Sea Island cotton is not, however, used to any extent in the electrical industry on account of its cost.

The cloth used as a base for varnished cotton cloth (frequently known as Empire Cloth) is produced from Egyptian or superfine American yarn, the counts employed being in the neighbourhood of 50 to 70. The weave is of considerable importance in these cloths. British manufacturers appear to favour a straight weave with 68 to 72 threads per inch weft, and 72 to 76 threads per inch warp, whereas continental and American producers frequently employ straight woven cloths having as much as 86 threads per inch weft, and 96 threads per inch warp. These closer woven cloths are better mechanically when cut into tape form. Table V shows some characteristics of typical

TABLE V
CHARACTERISTICS OF TYPICAL UNTREATED COTTON CLOTHS

Material.	Threads per inch.		Thickness in Mils.	Tensile Strength, lb./in. Width.	
	Warp.	Weft.		Warp.	Weft.
Cotton Cambric	85	65	3-4	16	9
Cotton Duckcloth	44	40	19-20	100	50
Calico	70	60	3-4	35	20
Superfine Cambric	—	—	—	—	—
Linen Cloth	60	44	11-13	105	100
Japanese Silk	130	110	1½-3	15	12
Artificial Silk	—	—	—	—	—
<i>Cotton Tape—</i>					
Ordinary ¼ in. to ½ in.	90	40	3½-4½	50	—
Ordinary ¾ in. to 1 in.	65	40	3½-5½	35	—
Superfine ¾ in.	—	—	—	—	—
<i>Linen Tape—</i>					
Ordinary ⅝ in. to ½ in.	56	28	6-8½	55	—
Ordinary ¾ in. to ½ in.	56	28	6-8½	50	—
Surgical Cotton Tape	—	—	13-17	90	—
Linen Webbing	—	—	18-22	120	—

<i>Binding Materials.</i>	<i>Tensile Strength in lb.</i>
Manilla Rope, ¼ in. diameter	600
Loom Twine, ⅛ in. diameter	50
Loom Twine, ⅜ in. diameter	60
Loom Twine, ½ in. diameter	90
Gillings Twine No. 10	50
Gillings Twine No. 12	25
Finishing Twine, ⅜ in. diameter	13
Gillings Treated Twine, ⅜ in. diameter	180



FIG. 5.—Some Untreated Tapes and other Binding Materials after Tensile Tests.

untreated cotton cloths (Egyptian cotton can be spun up to 120 count, but this is finer than generally used in the production of insulating fabrics).

Linen cloth is not employed as an alternative to cambrics, calicoes, etc., owing to its cost.

Japanese Silk.

Japanese silk cloths are extensively used as carriers for flexible mica insulation, and also for varnishing to produce varnished silk cloth (Empire Silk). The thickness of Japanese silks available varies from 1.5 mils to 2 mils, although this material is almost invariably bought under a specification defining number of mommes per square yard (the momme is a Japanese weight equivalent to 3.79 grammes).

Canvas, Duckcloth, Etc.

Canvas and duckcloths are the strongest form in which linen and cloth fabrics are available. They differ from cambrics and cotton calicoes in that they are woven with folded yarns. Characteristic figures for the strength of these materials are shown in Table V. In insulation work, these cloths are used for shrouding armature windings and as an external protection for insulation parts. For the majority of purposes, cotton duckcloths are sufficiently good, but an advantage can be procured by the use of linen, since this material is considerably stronger than cotton when tested at right angles to the warp.

Untreated Tapes and Webbing.

Untreated insulating tapes are produced in a number of forms; Fig. 5 shows a number of typical untreated tapes. The straight woven tapes are extensively employed where the tape part is to be varnished over subsequently with an insulating varnish. A large amount of straight woven tape is also used for rough binding purposes. Where a stronger and more durable tape is required, as for instance, for finishing field coils, etc., surgical tape or a webbing material is more frequently used. The strengths of various tapes are shown in Table V.

The untreated tapes at present used are almost exclusively

produced from cotton, although many materials of this kind are offered under the name of "linen" tape in order to satisfy a prejudice which seems to exist in favour of the latter material.

Wire Coverings.

Cotton and silk yarns are extensively used for covering and braiding wires. This subject is, however, separately dealt with in Chapter V.

TREATED FABRICS AND TAPES

Varnished Cloths and Silk Cloths.

Cotton calicoes and Japanese silks are very extensively used as varnished cloths. As already pointed out, a cloth with 68 to 72 threads on the warp and 72 to 76 threads in the weft is usually employed. It is essential in cloth intended for this purpose that the carding process should be complete, since any impurities left in the cotton, such as pieces of cotton hull, produce uneven cloth, which may subsequently be the cause of an electrical breakdown. Varnished cotton calicoes are very frequently sold as varnished linen cloth, but cloths actually made from linen are practically never produced.

Cloths intended for varnishing should be as free as possible from failures, and, where an extremely glossy and smooth finish is required, the nap should be removed from the cloth by singeing and calendering. Heavily calendered cloth, on the other hand, is to be avoided, since this process is liable to bruise the fibres and weaken the tensile strength of the cloth.

There has been considerable difference of opinion in the past as to whether cloth should or should not be protected with a starch dressing before varnishing, since such a treatment results in the finished product being virtually two films of varnish separated by a layer of cloth and starch. The alternative is to allow the varnish to permeate right through the cloth, but this latter practice results in a very uneven cloth, and one which shows serious loss of mechanical strength after ageing, so that practically all varnished cloths are now treated with special starches before varnishing, in order to protect the fibres from the action of organic acids liberated during oxidation of the varnish employed.

Only pure starches, as for instance, those prepared from potato, wheat, corn, etc., are used for these purposes. Before dressing with starch, the cloth is generally bleached and scoured to remove any sizing and filling which may have been put in by the manufacturers.

In general, one of two kinds of varnish is employed, resulting in either a yellow or a black finished product. The yellow varnishes employed are produced from linseed oil or China wood oil, with a small amount of either natural or synthetic resin. Such varnishes are thinned down with benzine to a specific gravity of 0.89 to 0.9 for using in the varnishing vats.

Black cloth varnishes are also produced, using either linseed oil or China wood oil as a base, but with asphaltum mixed in place of the resins employed in yellow varnish. Varnishes of this kind are also thinned with benzine to a specific gravity in the neighbourhood of 0.85 to 0.87, for using in the varnishing vats.

The actual process of varnishing is carried out by passing the prepared cloth through vats of varnish, after which it is made to ascend vertically through towers, in which the temperature is carefully controlled. The temperature usually employed is in the neighbourhood of 105 to 115° C., although for any individual varnish it should not be allowed to vary more than 1 per cent up or down where a uniform product is desired. The cloth returns down the towers and reaches the bottom in a condition sufficiently dry to be either rolled directly or passed forward to the maturing department, where it is freely exposed to the air at ordinary room temperature until the varnish has completely matured.

Varnished cloths are produced on rolls 36 in. or more wide, which are not infrequently slit in order to split the material into tape form. Such tapes, however, when cut from straight woven cloth, do not possess the property of stretching to leave clean corners when taping irregular shaped conductors, hence bias cut tape is generally called for by electrical manufacturers for this purpose. Bias cut tape has in the past been produced by cutting the raw cloth at an angle of from 30° to 60° to the warp and re-stitching together, so that the weft is at the

corresponding angle to the length of the re-stitched roll of cloth. The disadvantage of this arrangement has been the presence of joints every few feet in the material, even although many makers have utilized a special machine for making these joints with the edges of the material butted together. This disadvantage has been obviated by some manufacturers, who are utilizing cloth made in the form of a continuous woven tube, which may be cut to produce an unbroken length of cloth with all the threads on the bias. After varnishing, the bias cut tape is slit into the requisite width. The serious disadvantage to this new method lies in the difficulty of dressing the material and calendering before varnishing.

Varnished cotton cloth finds a wide range of uses as an insulator, particularly as a tape for taping end connections and in power transformer work. Until recently it was also frequently used as slot insulation on conductors in large machines. Table VI gives some indication of the properties of this material.

TABLE VI
PROPERTIES OF TREATED FABRICS

Name of Fabric.	Thick- ness in Mils.	Density in Gms. per Sq. Metre.	Tensile Strength per 1 in. Width.		Ashcroft Burst- ing Strength.		Average Electric Strength (Min. Val.) at 90° C.	Strength, Tearing E.R.A. Test.
			Warp.	Weft.	Normal Con- dition.	Aged for 4 weeks, 90-95° C.		
Varnished Cloth .	5	162	14 oz.	14 oz.	70	40	600 V/mil.	15 oz.
(Empire Cloth) .	7	219	16 "	16 "	100	50	550 "	20 "
Varnished Silk .	3	85	7 "	7 "	30	20	750 "	12 "
Varnished Silk .	5	142	10 "	10 "	50	35	700 "	16 "
Varnished Canvas	20	450	25 "	25 "	> 140	> 140	300 "	> 40 "
Varnished Paper (Manilla) .	3	110	—	—	9	4	700 "	9 "
Varnished Paper (Manilla) .	5	188	—	—	12	5	650 "	11 "

Varnished Japanese silk is also produced by the above described processes, and is extensively used on high tension insulation and for similar work. This material, as will be seen from the figures in Table VI, possesses a relatively high electric strength. Varnished silk tape is not, as a rule, produced on the bias, since this material is sufficiently elastic

when cut from the straight woven cloth. Linseed oil varnishes, with either natural or synthetic resins, are most generally employed for varnishing silk. All rolls of varnished fabrics or varnished tapes should be sealed with paraffin wax, particularly at the ends, before dispatch from the makers' works, in order to exclude air and prevent premature ageing.

Adhesive Tapes.

Adhesive tapes are produced in a number of ways, but all essentially consist of a strong cotton fabric which has been treated with a solution of rubber or bitumen, with thinners and suitable non-drying oils. The fabric is treated in its full width and afterwards slit into tape form. The best adhesive tapes for ordinary manufacturing purposes are made with rubber, which should be "frictioned" into the material by passing through special calenders. Such tapes are known as "friction" tapes, and are infinitely superior to "dipped" tapes, which are produced by simply passing the material through a vat containing a solution of rubber (or bitumen), and thence under a "doctor," which scrapes the coating down to its required thickness. This latter process does not secure complete filling of the fabric with the plastic material, and also seldom results in as thin a tape.

Adhesive tapes should appear tacky and adhesive at room temperature, and retain this property as long as possible on exposure to air. A strip of tape hung indoors and protected from the direct rays of the sun should show no diminution of tackiness at the end of two months.

So far no recognized British specification is apparently in existence for this material, but the following extract from the U.S.A. Navy Department Specification, dated 11th July, 1910 (No. 17T1), is of interest—

The surface must be smooth, the body entirely free from holes, the edges straight without ravelling, and the width uniform. When unwinding from the original coil, there must be no tendency to leave a thread sticking to the next layer. When held before a strong light, there must be no evidence of pin holes. The cotton to be well saturated, but the compound must not be put on in excess. The separation under a pull of 2 lb. per inch width applied to a coil wound on a $\frac{1}{4}$ in. mandrel, under a tension of 10 lb. at 75° F. shall not exceed 4 in. per minute. After ageing at 210° F. for sixteen hours it shall show a separation of not

exceeding 3 in. per minute at 75° F. under a tension of 1 lb. per inch width, when wound in a coil on a $\frac{1}{4}$ in. mandrel immediately after removal from the source of heat. The weight of the compound applied to the fabric shall be about 0.65 lb. per square yard. The ash on burning shall not exceed 45 per cent. The tensile strength at 75° F. shall not be less than 40 lb. per inch of width, when performed on a rubber testing machine, the initial distance between the clamps being 3 in., and the rate of separation 3 in. per minute. The dielectric strength shall not be less than 1,000 volts per millimetre thickness (5 minims). No breakdown shall result between two brass balls 2 cm. in diameter at the specified alternating potential having an effective value at a frequency of 60 cycles, applied continuously for five minutes. In making the test the electrodes must be brought close together so that the tape will just move between them. The tape shall be packed in tissue paper or tinfoil and enclosed in a tin box, to prevent it from drying out.

The last sentences in the above specification are of particular importance. Many tons of tape are wasted annually, due to its becoming dry when stored for long periods.

For certain open air work and positions where heavy tapes are required, bitumen-coated adhesive tapes find an extensive application.

List of Products and Trade Names of Materials dealt with as Fabrics and Tapes.

(Note: The terms quoted in inverted commas are from Curtes's *Glossary of Textile Terms*.)

CAMBRIC. "A light plain, cloth, fine reed, pick and yarns such as 100 × 80, 60s/80s. Both American and Egyptian yarns are used. It is difficult to say where a muslin ends and a cambric begins because of their great similarity. Cambric originally meant a fine linen cloth."

ITALIA INSULATING TUBING. Is a varnished cotton tubing made by Monte and Martini of Milan.

CELANESE. See Chapter XV.

EMPIRE CLOTH. A name originally used by the Micanite & Insulator Co., Ltd., to describe varnished cloths and silks produced by them at Empire Works, Walthamstow, but now generally used to describe varnished cloth products.

CALICO. "In Lancashire this name is applied generally to any plain woven cloth coarser than muslin. Originally it meant a printed cloth. The name came from Calicut (India) where the art of colour printing was first practised. Printed calicoes now generally pass under the name of chintz."

CANVAS. "There are many fabrics termed canvas. The principal kinds are—

"1. Cloths for embroidering (not used in insulation work).

"2. Java canvas (also not used in insulation work).

"3. A canvas which is shipped grey or finished and made from coarse

yarn, hard twist, about 8's warp and 12's weft, 40 ends, 34 picks in width, 26 in. to 32 in. in plain weave.

"4. Sail canvas, a stout built cloth from two-fold linen warp and coarse cotton weft.

"5. A dress canvas woven from linen warp and cotton weft such as 60's linen and 32's cotton, 74 ends, 76 picks, 39 in. wide. Dyed in many colours."

DUCKCLOTH. "A heavy cotton cloth used for purposes where strength and weight are required, such as for sails, boat linings, tent cloths, etc. The original duck was a linen cloth made from double warp and weft of coarse counts, but nearly all ducks are now made from cotton yarns, usually woven double ends and double picks. A light duck is made, which is bleached and used for men's clothing in tropical countries."

FELT. "A woollen fabric united without weaving by the application of heat moisture and pressure."

EXCELSIOR. A name used by Meirowski & Co. to describe a number of varnished fabric products including varnished cloth, varnished silk, bias cut tapes, and varnished tubes.

BLACKLEY TAPE. An adhesive tape produced by Connelly Bros., of Blackley, near Manchester.

CHAPTER V

CABLE INSULATION AND COVERINGS FOR WIRES

UNDER the heading of this chapter two highly important branches of the electrical manufacturing industry are included, each of which might be the subject of a monograph in itself. The following paragraphs are confined to a consideration of the materials used and a brief reference to the problems surrounding their application.

1. Cable and Lead-in Wire Insulation.

Cable insulation is conveniently grouped as used in—

(a) PAPER INSULATED POWER CABLES. The paper used in the insulation of paper insulated cables in general is almost exclusively “manilla,” or “pure manilla.” The former may contain some manilla fibre, but quite usually is made entirely from a highly refined sulphate wood pulp. Pure manilla, as its name implies, is made from pure manilla hemp. Some properties of these papers are given in Chapter III, Table II. The paper is applied to the stranded conductor as a tape (varying in width with the diameter of the conductor), which is usually applied with a quarter lap. The thickness of the paper used is from 4 to 6 mils for low tension work, and from 3 to 4 mils for E.H.T. cable work. The paper is always impregnated with an impregnating oil, either before or after “lapping” on. Resin oil is very generally used, suitably blended with rosin, paraffin wax, ceresin wax, etc., but somewhat naturally the exact nature of these “compounds” is regarded as a trade secret by cable makers. The two essential requirements in such compounds are high electric strength and permanent plasticity at air temperature, enabling the cable to be bent freely without cracking the insulation. In other words, bending must be permitted by the laminae of paper sliding over one another, since the paper itself is admittedly non-elastic. The thickness of the paper insulation

on cables up to 11,000 volts working pressure is laid down in British Engineering Standards Specifications Nos. 7 and 152.

The chief advantage of paper insulated power cables over cables insulated with other materials is their low capacity. This particularly applies on high tension work. Most engineers now agree that a high insulation resistance in paper insulated power cables is not a property to be sought after, since this is too frequently obtained at the expense of life and flexibility.

(b) RUBBER INSULATED POWER CABLES. Rubber insulated power cables have been in use from the earliest days of electrical engineering, and although for large power work and underground work this form of insulation has been largely superseded by paper, jute, and vulcanized bitumen, rubber insulation is still standard for small cables, lead-in wires, etc. Rubber insulation usually consists of three layers of rubber, the first of which is of pure Para rubber taped directly on to the tinned conductor. In the earliest days, before tinned conductors were generally used, a layer of paper was introduced between the rubber and the bare copper. This practice is still followed in some countries. The second layer of insulation is referred to as the "separator," and is made from less pure quality rubber mixed with a medium percentage sulphur, chalk, and other fillers ready for "vulcanization." The third and outer layer, or "jacket," is made from rubber with a still larger percentage of sulphur, and should be capable of being more completely vulcanized than the "separator" rubber, although very frequently little or no actual difference exists between these two layers. The cable is then taped with a cotton tape and vulcanized. The process of vulcanization unites all the layers and, theoretically at least, the covering is one in which the degree of vulcanization is graded down from complete vulcanization on the outside to pure unvulcanized rubber next the conductor. The thickness of the rubber insulation is laid down in B.E.S.A. Specifications, Nos. 7 and 152.

After vulcanization, the cable can either be braided with a coloured braiding and served with Ozokerite to produce a standard V.I.R. taped and braided lead-in cable, or can

be lead-covered, armoured, and otherwise finished off and protected for underground or outdoor use.

Special protective coverings, such as "cab tyre sheathing," maconite sheathing, etc., are very frequently called for. Fire-resisting braidings, utilizing both asbestos yarns or cotton yarns treated with tungsten salts, and other fire-proofing compositions, are used for traction and similar work.

Two other forms of rubber insulation are employed, particularly on small and cheaper grades of cables, flexible wires, etc. The method most commonly employed in Great Britain is to apply the rubber in sheet form to a number of conductors at once. The conductors, often as many as twelve in number, are passed side by side through special rolls, the rubber sheets being applied top and bottom and nipped between flanges on the rollers to surround the individual conductors. The whole emerges from the rollers as a corrugated sheet, which passes through a slitting machine to separate the cables before vulcanizing. The rubber sheet used is now generally composed of a very thin sheet of pure rubber calendered on to a sheet of vulcanizable material. After vulcanizing, the product is furnished with suitable outer protection in one of the ways already described. The second method, largely used in Germany, is to extrude the rubber covering in the form of a tube directly on to the conductor. Several layers are extruded on to the cable in order to secure the necessary thickness and yet ensure the conductor being central, it being found that it is almost impossible to guarantee accurate centring of the copper when extruding a thick wall in one operation.

(c) JUTE INSULATED POWER CABLES. Jute yarns, applied in the same manner as cotton is on cotton covered magnet wires, are very frequently employed in lieu of paper tape. Two-fold and three-fold yarns are employed, built up into superimposed layers laid in opposite directions to produce the necessary insulation thickness. (B.E.S.A. Specifications Nos. 7 and 152 also apply.) After applying the jute, the cable is vacuum dried and impregnated with compound similar to that used in the case of paper. The cable can be finished off with lead sheathing, armour, etc., in the same manner as

paper insulated cables. The chief advantage claimed for jute insulated cables is that they can be installed in a vertical position without the risk of the compound distributing itself again and causing "dryness" at the upper end of the vertical section. For mine work this is important, particularly where the temperatures are higher than those of the ordinary atmosphere.

(d) VULCANIZED BITUMEN INSULATED POWER CABLES. Vulcanized bitumen is applied as insulation to power cables by simply extruding the bitumen as a tube on to the stranded conductor. In building a three-core cable, the three individual conductors are first insulated and then, after laying up together, the whole is treated with another covering of bitumen which entirely fills up the air spaces between the three cores and gives the finished cable a circular cross section.

Some manufacturers fill the interstices between the strands in the core with a special flexible compound to exclude all air before applying the bitumen insulation.

Vulcanized bitumen insulated cables are largely used for colliery work, and recently have been employed on high voltage underground work.

(e) PAPER INSULATED TELEPHONE CABLES. The vast majority of large modern telephone cables are of the so-called dry core air-spaced type, for which the use of untreated dry paper insulation is almost universally adopted. The main point of difference is in the application of the paper, which can be either loosely applied as a spiral lapping or wrapped on the conductor longitudinally (usually in the form of a triangular cell) and secured with a whipping of cotton thread. In the lapped cables, double lappings are not used. Different coloured papers are employed to produce circuit distinctions. The paper used is a fine manilla paper. The insulated conductors are laid up in bundles, sometimes containing as many as 1,100 pairs of conductors, and are taped with either cotton tape or paper tape before vacuum drying and lead covering.

(f) DISTRIBUTION CABLES FOR TELEPHONE WORK. For house and office wiring of telephone systems, distribution cables are made up insulated either with double cotton covering or enamel and cotton covering, impregnated in either case

with waxes (ceresin, paraffin, etc.). The whole is then taped and sheathed with lead.

(g) RUBBER INSULATED TELEGRAPH CABLES. Rubber insulation has been used to a limited extent on telegraph cable work. Short submarine and river cables are frequently rubber insulated, the material being taped on, due to the difficulty of extruding good quality rubber.

(h) GUTTA-PERCHA INSULATED SUBMARINE CABLES. Gutta-percha was first used as an insulator for submarine cables by Walker, in 1849, in constructing the first Channel cable, although its use for this purpose was previously suggested by Wheatstone.

The process of applying the gutta-percha to the stranded conductor is similar to that adopted for vulcanized bitumen insulation, except that two and sometimes three separate layers are usually superimposed. After the gutta-percha has been applied, the cable is taped and given its armouring for protection in the water.

Although adopted so early in the history of the industry, gutta-percha has not been improved upon as a material for insulating submarine cables.

2. Coverings for Wires.

Under this heading is included the coverings for what are referred to in the industry as magnet wires, i.e. wires covered with one or more layers of cotton, silk, artificial silk, paper, asbestos, or enamel.

(a) COTTON-INSULATED WIRES. Cotton still remains the most popular wire covering, and single, double, and treble cotton covered wires form the material with which the majority of modern electrical machinery and apparatus is insulated. Designers have so far looked upon the untreated cotton yarn (which comprises cotton insulation on conductors) as a spacer between adjacent conductors which may ultimately be filled with an insulating varnish or impregnated compound to which higher insulating properties are ascribed. In other words, they regard the electric strength of the cotton insulation as being equal to that of an equivalent air film. Although it is not disputed that in many instances the cotton may be of

inferior insulating value to the varnish or compound, it is, nevertheless, itself a moderately good insulator, and it has recently been shown that, when employed either unimpregnated or after varnish treatment, its insulating properties can be very appreciably improved.

In Chapter IV, some information has been given with regard to the cotton fibre, and it was pointed out that the raw cotton fibre has in the past been converted into wire-covering yarn without being subjected to any washing treatment to remove the fatty impurities which exist on the raw fibre of a natural cotton. Lister, in *Journal, Soc. Chem. Ind.*, Vol. 21, page 388, shows an analysis of the wax impurity on cotton fibre, and points out that certain of these impurities are extremely hygroscopic, even to the extent of 32 per cent of their own weight. Matthews, in his book on *Textile Fibres*, suggests that the hygroscopic nature of untreated cotton fibre is probably due to this constituent, which, he points out, can be eliminated by the simple process of washing the cotton. Recent research has shown that, although simple washing is capable of effecting an astonishing improvement in the insulating value of cotton fibres, a still further improvement can be secured by subjecting the fibre to boiling with a very dilute solution of caustic soda (approximately 0.5 per cent). It has also been shown that certain growths of cotton possess electrical insulating characteristics more than twice as good as those of similar species of cotton grown in other localities.

It is reasonable to anticipate that further improvements along the above lines may be looked for in the near future in cotton-covered wires.

(b) SILK COVERINGS FOR WIRES. Silk-covered wires are almost entirely confined to the windings of small apparatus and instrument parts. The only reason for the use of this material for wire covering is that a thinner covering than that obtainable with cotton can be procured. Silk will not withstand temperature as well as cotton (as shown in Chap. IV) and has a considerably higher absorption factor. At the present time it is being largely replaced for fine coil work by enamel.

(c) ARTIFICIAL SILK. Artificial silk and so-called lustre

TABLE VII
CLASSIFICATION OF INSULATING VARNISHES

COMMERCIAL NAMES AND GENERALLY ADOPTED USES.	OIL VARNISHES.		ASPHALTUM VARNISHES.		SPIRIT VARNISHES.		PIGMENTED VARNISHES.	REMARKS.
	Oils alone.	Oils with Resins or Gum Resins.	Asphalts with Oils.	Asphalts with Petroleum Spirit.	Shellac, etc., a Soft Copals with Spirit Solvents.	Synthetic Resins with Spirit Solvents.	Oil Varnishes with Pigments.	
<i>Cloth Varnishes</i> for manufacture of varnished cloths, tapes, tubing, etc.	Linseed China wood	Linseed with copals thinned with petroleum spirit, solvent naphtha, or turps	Asphaltum with linseed thinned with turps or petroleum spirit	—	—	—	—	
<i>Dipping Baking Varnishes</i> for dipping coils, armatures, & general use. <i>Oven Drying</i>	—	As above	As above	Asphaltum dissolved in petroleum spirit	Shellac (or other grade of lac) dissolved in meth. spirit	Synthetic resin dissolved in acetone, a methylated spirit	Oils with copals, etc., with litho pone or other pigments for increasing thermal capacity, acid resistance, etc.	
<i>Dipping Air Drying Varnishes</i> for dipping coils, armatures, etc., where oven drying is not possible	—	As above, but with higher percentage of driers	As above, but with higher percentage of driers	As above	As above	—	As above	
<i>Impregnating Varnishes</i> for impregnating coils, armatures, etc., under pressure after vacuum drying	Linseed for impregnating wooden parts	Linseed with copals thinned with petroleum spirit, solvent naphtha, turps, etc. (Special slow surface oxidation, Sp. Gr. .870-.880. Vis. Red 40-50 min.	Asphalts dissolved in oils, wax taling, etc., and used hot	—	—	Synthetic resins dissolved in acetone and meth. spirit. Sp. Gr. .980-1.000. Vis. Red 60-80 min.	—	
<i>Finishing Air-drying Varnishes</i> for painting and spraying coils, finished machines, etc.	—	Hard coats with linseed, etc., for imparting a fine finish on apparatus. Thinned with petroleum spirit.	Asphaltum with linseed, etc., for slow drying, flexible and waterproof finishes. Thinned with petroleum spirit	Asphalts dissolved in petroleum spirit	Shellac dissolved in methylated spirit and suitably dyed	As above, but seldom used	Oils, copals, etc., with pigments used for protecting from acid fumes, etc.	NOTE. — <i>Amber-oil</i> finishing varnishes are very little used in the elec. indus. and are therefore omitted
<i>Mica Sticking Varnishes</i> for manufacture of micanite, mica cells, mica-folium, mica silk products, etc.	—	—	As above (specially used for making of cells for machines subject to vibration). Sp. Gr. .850-.900 Vis. Red 45-55 min.	—	Soft copals with methylated spirit. ¹ Sp. Gr. .860-.870. Vis. Red 7-10 min. Shellac with meth. spirit. ² Sp. Gr. .920-.950. Vis. Red 50-60 min.	—	—	¹ Castor oil is often added to give flexibility ² Varnish is thinned for finishing off micanite, mica-folium, etc.
<i>Varnishes</i> used as <i>Cements</i> in making varnish-paper boards, tubes, etc.	—	Linseed with small quantities of copals	—	Asphalts dissolved in petroleum spirit	Shellac with small quantities of copals in meth. spirit	Synthetic resins dissolved in acetone, meth. spirit, etc.	—	
<i>Gore Plate Varnishes</i> for insulating armature and transformer steel punchings	China wood	Copals with small quantities of linseed oil	—	—	Has been used, but not general	—	—	

TABLE VI

No.	Date		Time		Place		Remarks	
	Month	Day	Hour	Minute	Latitude	Longitude	Altitude	Remarks
1	Jan	1	10	00	10° 00' N	100° 00' W	1000	Clear
2	Jan	2	10	00	10° 00' N	100° 00' W	1000	Clear
3	Jan	3	10	00	10° 00' N	100° 00' W	1000	Clear
4	Jan	4	10	00	10° 00' N	100° 00' W	1000	Clear
5	Jan	5	10	00	10° 00' N	100° 00' W	1000	Clear
6	Jan	6	10	00	10° 00' N	100° 00' W	1000	Clear
7	Jan	7	10	00	10° 00' N	100° 00' W	1000	Clear
8	Jan	8	10	00	10° 00' N	100° 00' W	1000	Clear
9	Jan	9	10	00	10° 00' N	100° 00' W	1000	Clear
10	Jan	10	10	00	10° 00' N	100° 00' W	1000	Clear
11	Jan	11	10	00	10° 00' N	100° 00' W	1000	Clear
12	Jan	12	10	00	10° 00' N	100° 00' W	1000	Clear
13	Jan	13	10	00	10° 00' N	100° 00' W	1000	Clear
14	Jan	14	10	00	10° 00' N	100° 00' W	1000	Clear
15	Jan	15	10	00	10° 00' N	100° 00' W	1000	Clear
16	Jan	16	10	00	10° 00' N	100° 00' W	1000	Clear
17	Jan	17	10	00	10° 00' N	100° 00' W	1000	Clear
18	Jan	18	10	00	10° 00' N	100° 00' W	1000	Clear
19	Jan	19	10	00	10° 00' N	100° 00' W	1000	Clear
20	Jan	20	10	00	10° 00' N	100° 00' W	1000	Clear
21	Jan	21	10	00	10° 00' N	100° 00' W	1000	Clear
22	Jan	22	10	00	10° 00' N	100° 00' W	1000	Clear
23	Jan	23	10	00	10° 00' N	100° 00' W	1000	Clear
24	Jan	24	10	00	10° 00' N	100° 00' W	1000	Clear
25	Jan	25	10	00	10° 00' N	100° 00' W	1000	Clear
26	Jan	26	10	00	10° 00' N	100° 00' W	1000	Clear
27	Jan	27	10	00	10° 00' N	100° 00' W	1000	Clear
28	Jan	28	10	00	10° 00' N	100° 00' W	1000	Clear
29	Jan	29	10	00	10° 00' N	100° 00' W	1000	Clear
30	Jan	30	10	00	10° 00' N	100° 00' W	1000	Clear
31	Jan	31	10	00	10° 00' N	100° 00' W	1000	Clear

coverings for wires have been applied to a limited extent. The material is also used in conjunction with cotton, the first covering being either artificial silk yarn or a narrow tape. Experience with these coverings has shown them, on the whole, to be very little improvement, if any, on cotton covering of an equal thickness, but electrical tests on any wire coverings which are applied in the form of yarns or tape are misleading, since the breakdown voltage is frequently affected by the presence of air spaces. For this reason, comparative figures on these coverings are not quoted here.

The suggestion, which it is understood has already been experimented with, of applying the material from which artificial silk film is produced in the form of a varnish directly on to conductors, is probably a step in the right direction, and it may be anticipated that an advance of this nature may mark the next few years. As will be seen from Chapter XV, artificial cellulose products of this nature can be produced with a water absorption as low as 11 per cent, therefore comparing favourably with both natural silk and cotton. Celanese (produced by Celanese Ltd., of Spondon and London) has been most satisfactorily employed in this connection, and its use as an alternative to natural silk is recognized by the leading authorities.

(d) PAPER COVERINGS FOR WIRES. Paper coverings for wires have already been referred to in dealing with cable manufacture. Paper insulation has much to be said in its favour for wires intended for use as windings on high tension transformers where immersed in insulating oil, since this form of covering can be built up to a considerable thickness very much more readily than any insulation material applied in the form of yarn. Paper-insulated wires for transformer work are not infrequently lapped with as many as 15 or 20 layers of 3 or 4 mil paper. Experience has shown that paper-insulated wire *for this purpose* should be treated with mineral insulating oil to obtain the best electric strength figures, if the final product is also to be used in a similar oil.

Paper-insulated wires are not used to any extent in other sections of the electrical industry.

(e) ASBESTOS COVERINGS FOR WIRES. Asbestos coverings

for magnet wires have been used in machinery and apparatus where high temperatures are liable to occur for a number of years. Until recently these coverings usually took the form of thin asbestos tape lapped on next to the conductor, secured in position and protected by a single cotton covering. More recently a number of wires have been put on the market in which the asbestos has been applied to the wire as pulp, and has been ironed or otherwise moulded by dies, so as to produce a matted uniform covering. In wires of this type some form of adhesive is necessarily employed in preparing the asbestos pulp, in order to assist it to lie uniformly and possess mechanical strength when the wires are bent. Bituminous products and mineral waxes have been employed for this purpose. Even in this form of covering a single cotton strand is usually applied spirally along the wire in order to act as an " anchor " for the pulp covering.

Wires covered in this way are capable of operating at the highest temperatures met with in machinery built to B.E.S.A. ratings for Class B insulated machines. In this respect, these wires are superior to those in which the asbestos is applied in tape form and secured by a layer of single cotton covering, since in the latter it is difficult to make sharp bends on the wires without causing the adjacent lappings of tape to separate.

Asbestos is also applied to wires in the form of yarn, but this particular application is at present almost exclusively confined to the coverings for wires employed as leads to domestic heating and cooking apparatus, and also in the wiring of kinema searchlight equipment.

(f) ENAMELLED COVERINGS FOR WIRES. Enamel covering for wires is rapidly earning popularity, not only for the smaller magnet wires employed on instrument and apparatus work, but also on larger sizes. In the latter case, however, the enamel coating is not infrequently protected with a single layer of cotton. The process of enamelling wires consists in passing the wire through vats containing the enamel, and thence upwards through heated tubes in which the enamel is baked at a temperature in the neighbourhood of 600°C . This high baking temperature, being only slightly below the annealing temperature of copper, is the cause of very considerable

trouble, particularly on the thinner sizes, because the wire stretches easily during the process, and thus both diameter and electrical resistance are reduced. The enamel used is generally a China wood oil base varnish, blended with special resin.

Standard Specifications.

Insulated cables and wires are the subject of the following B.E.S.A. Specifications—

7-1922 Copper conductors, insulated, annealed for electric power and light, dimensions of.

152-1922 Ditto in metric measure.

156-1922 Enamelled plain copper wire for electric instruments and apparatus, dimensions and resistances of.

List of Products and Trade Names of Materials dealt with as Cable Insulations.

MACONITE. A material resembling rubber made by the Macintosh Cable Co., Ltd., and used as a cable insulation.

CAB TYRE. A strong flexible rubber covering manufactured by the St. Helens Cable & Rubber Co. and other cable makers. The chief characteristic is capability of withstanding rough usage.

CHAPTER VI

INSULATING VARNISHES AND SOLVENTS

INSULATING varnishes constitute one of the most important items in the insulation of electrical machinery, since they enter into almost every insulated part of modern electrical plant, and in the majority of cases even quite small variations in their constitution or properties result in failure of the entire plant. On the whole, the electrical industry is fortunate in being able to secure its varnish requirements from manufacturers who are able to give a series of uniform products, year in and year out, without a suspicion of change. This fact may lead to the erroneous impression that insulating varnishes are easy to produce with unfailing uniformity of quality, but, in actual fact, the blending of resins, gums, and oils which go to produce a good, clear insulating varnish, calls for years of experience.

Insulating varnishes may be classified as follows—

(a) OIL VARNISHES, as a general rule made from boiled and blown linseed oil blended with resins, gums, and driers. Practically all dipping and impregnating baking varnishes belong to this class. China wood (or tung) oil is also used largely in view of its moisture and heat resisting properties.

(b) ASPHALTUM VARNISHES, chiefly made from native asphalts dissolved in benzine (petroleum spirit). Asphalts (both native and pyrogenous residues) are also used dissolved in mineral oils, wax tailings, etc., for impregnating purposes, although in this form the material can hardly be regarded as a varnish.

(c) SPIRIT VARNISHES (including synthetic resin varnishes) are chiefly used as finishing varnishes where stove drying is impracticable, and for mica sticking purposes. The majority of spirit varnishes consist of lacs (shellac, garnet lac, etc.), dissolved in denatured alcohol, acetone, etc.

(d) PIGMENTED VARNISHES, which class includes oil varnishes

loaded with lithopone and various pigments to improve the thermal and sometimes the filling characteristics of the varnish.

Table VII is intended as an effort to classify the above varnishes according to their various applications in insulation work, but it is recognized that there must be many exceptions to a general classification of this nature.

MATERIALS USED IN THE MANUFACTURE OF INSULATING VARNISHES

Oils.

The oils used in varnish making are almost exclusively vegetable oils and are sub-divided into—

(a) DRYING OILS, which include oil containing glycerides of certain fatty acids.

(Linseed oil, China wood oil, poppy seed oil, etc.)

(b) SEMI-DRYING OILS, which possess drying properties to a limited extent.

(Cotton seed oil, soya bean oil, etc.)

(c) NON-DRYING OILS, which are not capable of oxidation in the manner of drying oils.

Castor oil is the non-drying oil generally used in the manufacture of insulating varnishes to secure permanent flexibility.

Drying Oils.

LINSEED OIL. Linseed oil is extracted or expressed from the seed of the flax plant, *Linum usitatissimum*, although, as a matter of fact, the fibre obtained from plants grown for the production of seed is so poor that, as a general rule, it can only be employed for the manufacture of tow, paper making, etc. The oil is most generally expressed from the seed in heavy hydraulic presses. This expression of the oil is seldom complete, since the practice is generally followed of leaving 10 per cent or 15 per cent of the oil in the seed, so that the latter may be used as cattle food.

The general characteristics to be expected in a pure linseed oil are shown in Table VIII.

TABLE VIII
GENERAL CHARACTERISTICS OF INSULATING OILS

	DRYING OILS.						SEMI-DRYING.		NON-DRYING.		ROSIN.
	Perilla Oil.	Linseed Oil.	Hemp Seed Oil.	China Wood Oil.	Poppy Seed Oil.	Cotton Seed Oil.	Soya Bean Oil.	Castor Oil.	Olive Oil.	Rosin Oil.	
Oil Content of Seed	36%	38-40%	30-35%	40-41%	41-50%	24-26%	18%	46-53%	45-55%	—	
Colour of Oil	Yellow	Light ¹ yellow	Light green to brown	Pale ² yellow	Colour ³ less or pale green	Yellow brown to ruby	Dark brown	Colourless or pale green	Golden to dark green	Brownish yellow	
Specific Gravity 15° C.	.930	.934	.926	.938-.942	.925	.923	.925	.960	.917	.970-.985	
Saponification Value.	189.5	192.5	192.5	193	194	194	192	185	192-198	—	
Iodine Value	206	186	148	160-175	135	106-110	121-133	84.5	85-100	100-125	
Refractive Index at 15° C.. . . .	1.482	1.481	1.478	1.510	1.458	1.475	1.475	1.479	1.473	1.537	
Refractive Index on Zeiss Butro-refractometer	—	71.0	—	—	64	—	62.9	58.5	55.5	—	
Unsaponifiable Matter	—	1.3	—	0.75	0.5	1.2	1.0	—	1.1	—	
Solidifying Point °C.. . . .	—	-25	-15 to -17	below -17	-18	3 to 4	-8 to -15	-10 to -12	10 to -6	—	

¹ The colour of linseed oil varies considerably.

² When produced by hot pressing method the oil is considerably darker and is sold as "Black Tung Oil."

³ A hot pressed oil is darker and is sold as "Red Poppy Seed Oil."

The colour is shown as golden straw, but this only applies to oil pressed from matured dry seeds, since the oil becomes muddy when pressed from freshly-gathered seeds.

Linseed oil is by far the most important oil used in the manufacture of varnishes, and in most varnishes, although it may be considered as a solvent, it really constitutes the base of the product, since the oil itself possesses the property of oxidizing and producing a hard, insoluble, and impervious skin.

Livache and McIntosh, in the *Manufacture of Varnishes and Kindred Industries*, Vol. II, give a very complete explanation of the changes which take place when linseed oil becomes oxidized. The hardening process is traceable to the presence of glycerides and the rapidity with which the change takes place is proportionate to the approximation in composition of the glycerides to that of a linolein, which is itself a glyceride formed by the combination of glycerine with linolic acid. When the linolein comes into contact with oxygen, either from the air or from oxygen-producing dryers included in the varnish, it becomes transformed into what is known as linoxyn. The latter is insoluble in ether, and also in commercial solvents used in varnish work, and, as already stated, is itself the basis of a good varnish coat.

For the production of the best varnishes, linseed oil should be matured for at least one year before it is used, and many manufacturers make a practice of subjecting even matured oil to a process of prolonged boiling before including it as an ingredient in their varnishes. It may be noted that since linseed oil is an expensive product it is very frequently subjected to adulteration, cotton seed oil, colza, resin oil, mustard oil, fish oil, etc., being some of the adulterating materials employed.

The presence of these cheaper oils can be detected by simple chemical tests, or more frequently by observations of the saponification number or the refractive index. Adulterated oils should never be used in the manufacture of insulating varnishes.

CHINA WOOD OIL (TUNG OIL OR WOOD OIL). Tung oil has been used from the earliest times in China for waterproofing

paper, fabrics, etc., and is to-day becoming increasingly important in varnish making for various purposes. This oil is expressed from the seed kernels of the fruit of a number of species of *Aleurites*. By far the greatest quantity of wood oil comes from the fruit of *Aleurites Fordii*, although Canton wood oil is obtained from *Aleurites montana*, and Japanese wood oil is generally derived from *Aleurites cordata*.

The average characteristics to be expected in a good grade of China wood oil are shown in Table VIII.

POPPY SEED OIL. Poppy seed oil is expressed from the seeds of the opium poppy (*Papaver somniferum*) and is produced in China, France, and India. The general characteristics in an average sample of poppy seed oil are also shown in Table VIII.

Semi-drying Oils.

COTTON SEED OIL. Cotton seed oil is pressed from the "hulls" which remain after the separation of the cotton fibre from the seed heads of cotton plants (*Gossypium* species). The oil is extensively used as a food, but is also employed to a certain extent in varnish making. The general properties of this oil are also shown in Table VIII.

SOYA BEAN OIL. Soya bean oil is extracted or expressed from the soya bean (*Soya Hispida*), which is extensively cultivated in Northern China, Manchuria, and Korea. Like cotton seed oil, this oil has been extensively used for food. Its use in this connection has been known for many thousands of years, but more latterly it has been employed for varnish making.

Some details of this oil are included in Table VIII.

Non-drying Oils.

CASTOR OIL. Castor oil is the most important non-drying oil as far as the varnish industry is concerned. This oil is expressed from the seeds of the castor oil plant (*Ricinus communis*), which is largely grown in India and Brazil, although smaller quantities are obtained from other countries in Eastern Asia. This oil is extensively used, particularly for aeroplane engines, as a lubricant where high viscosity is of importance.

It is frequently added to insulating varnishes in order to prevent them drying hard and to render them more or less permanently flexible.

The characteristic properties of this oil are shown in Table VIII.

OLIVE OIL AND ALMOND OIL. Both of these neither thicken nor harden under the influence of oxygen, and therefore have been used as non-drying oils in the manufacture of varnishes, but their use cannot be regarded as general.

ROSIN OIL. Rosin oil is extensively used as an impregnating oil in the manufacture of paper-insulated cables on account of its penetrating power and its high electric strength, and therefore may be included here. This oil is obtained by the distillation of rosin. Good rosin oil has no drying properties and is a poor conductor of heat.

The general properties of rosin oil are shown in Table VIII.

RESINS, GUMS, AND ALLIED PRODUCTS

Resins.

Resins are the oxidation (or the hydration) products of the essential oils found in certain plants—particularly coniferous trees. The essential oils first appear as such in the protoplasmic cells of the tissue. These cells form a special part of the plant and frequently converge and expel the essential oil into so-called secreting vessels in the tissue, where they become oxidized and form stable compounds known as resins. When the oxidation is only partial, much of the essential oil remains a liquid and the product is called an "oleo resin." The resins used in varnish making vary very considerably in their various properties, some of which are shown in the Table IX. The hardness of resins is closely related to solubility and, generally speaking, the softer a resin the more easy it is to dissolve. The very hard resins can only be satisfactorily dissolved by heating to such an extent as to commence fractional distillation, when resinous oil is driven off, allowing the resin to dissolve in linseed oil or other solvents.

Resins may be broadly classified under the headings given

TABLE IX
PROPERTIES OF RESINS

Name of Resin.	Geographical Source.	Botanical Origin.	State in which Found.	Sp. Gr.	Melt- ing Point °C.	Percentage Solubility.			
						Meths.	Acetone.	Benzine.	Turps.
I. HARD COPALS :									
Zanzibar . .	East Africa	<i>Trachylobium Hornemannianum</i>	Fossil and recent	1·058	265	15·8	22·7	11·7	insol.
Madagascar .	"	<i>Hymenoea verrucosa</i>	"	1·056	300	20·4	35·7	21·6	39·7
2. MEDIUM COPALS									
Accra . .	West Africa	—	"	1·033	145	37·2	54·2	33·1	21·3
Red Angola .	"	<i>Copaifera mopane</i>	Fossil	1·067	315	32	32·3	30	23
White Angola .	"	" <i>gorskiana</i>	"	1·055	95	53·3	39	49·5	30·6
Benzuela . .	"	"	"	1·058	165	53·1	75·2	34·4	31·2
Congo . .	"	" <i>demeussi</i>	"	1·073	195	44·7	54·2	39·9	31·3
Cameroon . .	"	—	"	1·080	140	22	39·5	28·2	21·4
Sierra Leone .	"	<i>Copaifera copallina</i>	Fossil and recent	1·060	130	50·8	59·7	43·1	28·6
3. SOFT COPALS :									
Demarara . .	Central America	<i>Hymenoea courbaril</i>	"	1·047	180	32·6	30·8	29·1	7·5
Columbian . .	South America	"	"	1·054	> 300	40	56·4	39·2	31·3
Brazilian . .	Brazil	"	"	1·053	100	69·8	62·4	59·5	51·8
Manilla (hard).	East India	<i>Dammara orientalis</i>	"	1·065	135	35·4	48	36·1	26·8
" (soft) . .	"	"	"	1·060	103	92·7	100	42·1	35·9
Kauri (pale) .	New Zealand	<i>Agathis australis</i>	Fossil & tapped	1·036	165	53·1	91·1	33·3	22·5
" (brown) .	"	"	Fossil	1·053	185	38·1	61·3	29·4	26·4
" (bush) . .	"	"	"	1·030		52·7	79·3	38·3	27·1
4. SUCCIN (Amber)	East Prussia	<i>Pinus succinifera</i>	"		286				
5. SANDARAC .	North Africa	<i>Callitris quadrivalvis</i>	"						
6. DAMMAR . .	Malay & E. Indies	<i>Agathis loranthifolia</i>	Fossil & tapped	1·05	108				
7. GUM MASTIC .		<i>Pistachia lentiscus</i>	Tapped						
8. ANIMÉ . .		<i>Hymenoea courbaril</i>	"						
9. ELEMI . .			"						
10. COLOPHONY .		Various trees—Order Burseraceae	"		108				

in the following paragraphs which, however, only cover the more important raw products used and are not intended as a complete classification including the numerous less important resins and gums.

(a) **HARD RESINS** (*frequently fossilized*). Hard resins are insoluble in water, and this class includes copals and succin.

(b) **GUM RESINS OR OLEO RESINS**, from which the gum constituents can be dissolved with water, leaving the insoluble resin behind. Among the gum resins which are used in the manufacture of insulating varnishes are elemi, dammar, mastic, sandarac, and the turpentine.

(c) **BALSAMS**, which may be defined as thick solutions of resins in essential oils, and which contain cinnamic and benzoic acids. Balsams are not used in the production of insulating varnishes.

Copals.

The general term "Copal," although originally applicable only to the fossilized copals of East Africa, is now broadened to cover the very large number of widely different resins, both fossilized and "recent."

Table IX shows the general properties of the more important copals, which have been grouped under the headings of hard, medium, and soft copals, in accordance with general practice employed in the varnish making industry. It may be pointed out that the copal probably most used in the good grades of insulating varnishes is Kauri copal.

Succin (Amber).

Succin is a fossil resin from ancient pine forests (*Pinus succinifera*), and is obtained almost exclusively from deposits on the shores of East Prussia.

It is extensively used in the manufacture of ornaments, pipe stems, etc., but also finds a limited use in the manufacture of insulating varnishes, where a particularly hard, glossy surface is required.

Table IX shows some properties of this resin.

Sandarac Gum.

Sandarac gum is the exudation from a North African tree (*callitris quadrivalvis*), and is frequently used in admixtures with softer resins to produce a hard, glossy varnish.



FIG. 6.—Resins used in the Manufacture of Insulating Varnishes.

Dammar Resins.

These resins are obtained from a number of trees growing in Malaya and the Dutch East Indies belonging to the natural order *Dipterocarpace*, and also from a coniferous tree (*Agathis loranthifolia*). Dammar is a soft resin, but

is particularly useful where pale colour is of importance. Dammar resins are frequently adulterated with colophonies.

Gum Mastic.

This resin is obtained from the tree *Pistachia lentiscus*, growing on the shores and islands of the Mediterranean Sea. It has a low melting point of 108°C ., and a density of approximately 1.05. It is readily soluble in turpentine, and is occasionally used in conjunction with other gums for varnish making.

Oleo Resins.

TURPENTINES. Turpentine is an oleo resin which is obtained by tapping various trees of the natural order *Burseraceae*. The turpentine has densities in the neighbourhood of 0.8 to 0.9, and contains from 15 per cent to 30 per cent of spirits of turpentine. The more important varieties of turpentine are, according to origin—

American turpentine, from the trees *Pinus palustris*, *Pinus torda*, and *Pinus cariboea* (Cuba).

French turpentine from *Pinus maritima*.

Russian turpentine from *Pinus sylvestris* (the so-called Scotch fir).

Spain, Portugal, Mexico, Central America, and many other countries also produce small amounts of turpentine, all, however, from trees of the genus *Pinus* (conifers), with the exception of wood turpentine extracted from the wood of the Douglas fir (*Pseudotsuga taxiflora*).

Other resins which may be classed in the same category with turpentine are elemi and Canada balsam, but neither of these are of commercial importance in the insulating varnish manufacture.

COLOPHONIES OR ROSINS. "Colophony," which term is to be preferred to that of "rosin," in order to avoid the possibility of confusion with the word "resin," is obtained from the same source as turpentine, and should really be considered as by-products remaining when the spirits of turpentine are distilled from the exuded turpentine as collected from the pine forests.

Colophonies are brittle materials, soluble in alcohol, ether, acetone, and carbon bisulphide. They melt at approximately 90°C. to 100°C. , and are frequently used as adulterants in other resins. They are, however, legitimately introduced into the production of certain insulating compounds.

LAC. Although frequently referred to as a gum, this is, strictly speaking, the product of an insect, *Tachardia (coccus) lacca*, which is closely related to the green fly familiar to British gardeners. The lac itself actually consists of excretions and secretions from the insect, and is built up to a considerable thickness on the branches of certain trees which are found in India, Indo-China, and Siam. The production of lac in its various forms is very largely in the hands of natives, and in the majority of cases is not regarded by them as a "main crop," and therefore receives very little attention. For this reason supplies of lac are extremely variable. In collecting shellac the twigs encrusted with native shellac are broken from the trees and the wood itself is roughly separated from the lac. In this form the material is referred to as stick lac. Stick lac is very seldom exported as such from India, but is crushed and sifted to produce so-called grain lac, which in turn is converted into one of the following three forms, in which lac reaches European and American markets—

(a) *Shellac*. Shellac is manufactured from grain lac by melting and straining through cloth in order to purify, after which the material is re-heated and stretched out into a thin sheet. The sheet, when cold, is easily broken up into the small flakes familiar as shellac. This material varies very considerably in colour and in other properties, depending upon the climatic conditions under which it is grown and on subsequent treatment which it has received.

Shellac is sold on the market under so many different proprietary marks that some definite specification is unquestionably necessary before any degree of uniformity can be expected. The London Shellac Trade Association has a quality clause for standard shellac contracts which reads—

Guaranteed to be of equal value to standard sample of T.N. and not to contain more than 3 per cent of adulterating matter, or if inferior thereto a fair allowance to be made—

but this clause loses its value since the standard sample of T.N. is dependent from year to year upon the quality of the first samples to reach London.

In his paper "Purchasing Specifications for Resins and Shellac—A Review of the Question," before the Oil and



FIG. 7. Shellacs.

Colour Chemists' Association (15th June, 1922), Mr. W. B. Parker makes a plea for recognizing six grades of shellac only and abolishing the multitude of descriptive and proprietary terms used by various suppliers. Mr. Parker suggests the following grades—

- (1) Lemon (yellow)—Pure.
- (2) Pale orange—Pure.

- (3) Orange—Pure.
- (4) Deep orange (T.N. standard, 3 per cent rosin wax).
- (5) Brown (U.S.S.A. and inferior 3 per cent to 10 per cent rosin).
- (6) Dark brown (resinous), 10 per cent to 15 per cent rosin.

NOTE. The naming "T.N." has been so long in existence that its origin is obscure. It is probably either the mark of Taluram Naturam of Belapur or Triloki Nath (Bengali).

"Machine" made shellacs are not accepted on Calcutta market as T.N. shellacs.

Bleached Shellacs have special applications only, and are generally produced in the country in which they are used, since bleached shellac rapidly loses its solubility unless kept under water.

(b) *Button Lac*. Button lac is manufactured from grain lac by melting and pouring in a special manner so as to produce flattened drops of the material, approximately 1 to 2½ in. diameter, resembling buttons in appearance.

Button lac comes on to the market in four grades—

- (1) Pure button lac, made from good grain lac.
- (2) Pure black button lac made from refuse remaining in the straining bags and dust from grain lac.
- (3) Button lac made from good grain lacs but containing 20 to 30 per cent colophony (rosin).
- (4) Black button lacs as in (2) but containing resin.
- (c) *Garnet Lac*. Garnet lac is generally made from inferior grades of grain lac and differs from shellac only in that it has not been stretched out into a thin film, but is left in slabs approximately ⅓ in. to ¼ in. thickness. Garnet lac almost invariably contains rosin, varying in amount from 5 to 20 per cent.

A certain amount of shellac is made in the Calcutta district of India, utilizing solvent methods for extracting the resin from stick lac. Shellac made by solvent method is already being used to a considerable extent in the electrical industry with apparent satisfaction. The chief advantage which can be claimed for material made in this manner is the fact that practically all the resin is recovered, even including low grades of stick lac and waste material.

Synthetic Resin (Bakelite).

The synthetic resins used in the production of insulating materials belong almost exclusively to the phenol-aldehyde group of products. As long ago as 1871 it was discovered by Bayer that phenols and aldehyde react. Many subsequent investigators produced resin-like products, including F. Bayer & Co., who produced a shellac substitute in 1907 using ortho cresol. Dr. Baekeland, in 1908, applied these principles, and the majority of the products of this type now on the market as insulators are made under his patent.

Pure phenol and pure formaldehyde react very slowly even under the influence of temperature, but when brought into contact with a catalytic agent—alkalis, usually ammonia, are used as catalysts—the action is much more rapid and resin is formed. The exact chemical changes through which the materials pass are still somewhat obscure, but it is generally agreed that the ammonia catalyst first reacts with the formaldehyde to produce hexamethylenetetramine, which becomes the active agent operating on the phenol to produce resin by a series of complex changes, which are referred to as “condensation” changes, because a certain amount of water is liberated. The resin is insoluble in water and acids, but soluble in alkalis. The change can be checked at any stage, thus Bakelite is available as a liquid only partially condensed (“A” stage), or a solid which will soften under the influence of heat (“B” stage), or a hard stable resin (“C” stage) incapable of being dissolved, except by alkalis, and unaffected by such temperatures as are encountered in electrical plant. The chemical composition of the resin in this final stage is: Carbon 74.4 per cent, oxygen 18.7 per cent, hydrogen 5.9 per cent. For the majority of insulation work the resin is utilized in its B stage, and is afterwards converted by a heating (frequently under pressure) at approximately 150° C, to its C stage.

It need hardly be pointed out that the use of this product as an insulator has to be very carefully watched, because an excess of any one of the ingredients is liable to cause subsequent trouble. Phenol (or cresol) is more or less always present, because the formaldehyde usually employed with them is so volatile that it is impossible to predetermine the exact amount

necessary to react with the phenol. This phenol is intentionally allowed to predominate as an impurity, since it is contended by many authorities that this reagent is not deleterious and actually assists in fluxing the resin under the influence of heat in building up insulation products. Ammonia should never be allowed to remain as a free impurity in synthetic resins for insulation work.

Cumarone Resin.

Cumarone resin is another synthetic product produced by the polymerisation of cumarone and indene (coal tar naphtha products) by the action of sulphuric acid. This resin was extensively employed in Germany during the war and has since found a number of commercial applications.

Duoprene.

Duoprene is a solid resin obtained by the chlorination of rubber. It is soluble in various rarer solvents, but is usually made into a varnish by dissolving in benzol and coal tar naphtha. The dry varnish film resists the action of acids, alkalis, alcohol, ether, petroleum spirit, or mineral oils, and therefore should find considerable use as a protective varnish covering for special purposes. In electrical work it has been applied for protecting busbars, switch parts, and as a finishing coat generally.

Asphaltums.

Bituminous products form the base of a number of excellent varnishes and impregnating compounds. These products are fully dealt with in Chapter XI.

Hard bitumens *only* are satisfactory for manufacturing varnishes, including hard nature asphalts, asphaltites, hard residual asphalts, and hard pitches. For impregnating compounds the materials employed need not possess the degree of hardness required for varnish making.

Lithopone.

Lithopone is a precipitate of zinc sulphide and barium sulphate in the proportions of $29\frac{1}{2}$ per cent and $70\frac{1}{2}$ per cent

respectively, prepared by mixing zinc sulphate and barium sulphide so that a chemical reaction represented by the formula $\text{ZnSO}_4 + \text{BaS} = \text{ZnS} + \text{BaSO}_4$ takes place. The precipitate is heated to dull redness and then plunged into water, after which it is ground to powder, washed and dried.

It is used as a pigment in many varnishes. Special heat-conducting properties are attributed to varnishes in which it is employed.

Solvents.

✓ The solvents generally used for the production and thinning of insulating varnishes are—

1. Alcohol, including ethyl alcohol, methyl alcohol and methylated spirits.
2. Petroleum spirit (benzine).
3. Spirits of turpentine.
4. Acetone.

Other solvents, including carbon bisulphide, solvent naphtha, benzene, benzol, etc., are sometimes utilized.

ALCOHOL. The most usual form in which alcohol is employed is that of industrial methylated spirits, which consists of spirits of wine rendered nauseous and undrinkable by the addition of 5 per cent by volume of wood naphtha or other substances or combination of substances sanctioned by the regulations in force in the country in which it is used. (*Note.*—It may be pointed out that methylated spirits sold by retailers in Great Britain contains twice the amount of wood naphtha permitted in industrial methylated spirits, and for this reason special permission has to be obtained in order to purchase the latter.) Industrial methylated spirits is a clear, colourless liquor, with a characteristic odour. Its physical properties are shown in Table X.

OTHER ALCOHOLS. In various countries, other forms of alcohols than methylated spirits are used in varnish making. Ethyl alcohol is frequently employed without any addition of other materials to render it undrinkable. It has been claimed that certain varnishes using this solvent are characterized by a very low acidity.

PETROLEUM SPIRIT (BENZINE) is produced by the distillation of crude petroleum and is a hydrocarbon with the formula (C_nH_{2n+2}), consisting principally of hexane (C_6H_{14}) and heptane (C_7H_{16}). Its physical properties are shown in Table X, though it should be pointed out that its boiling point is extremely variable and depends on the temperature of distillation at the time of manufacture. It is extremely inflammable and when exposed to air absorbs oxygen, its density and boiling-point being then raised. Benzine is closely akin to petrol (motor spirit), and the better grades of the latter are frequently used as thinners for insulating varnishes, although this is a practice which is open to criticism unless ample facilities are available for ensuring purity of the petrol used.

SPIRITS OF TURPENTINE. As has already been mentioned, spirits of turpentine are obtained by the distillation of turpentine in water vapour. This solvent has the general chemical formula $C_{10}H_{16}$. Table X shows some of the characteristic properties of spirits of turpentine.

Spirits of turpentine absorb oxygen and also become active catalytic agents, and, on account of the resinification of this solvent when exposed to air or light, it is generally considered advisable to utilize freshly-distilled spirits. Generally speaking, the two dextro-rotary spirits are preferred in varnish manufacture.

Since the present demand for spirits of turpentine far exceeds the supply, a great number of adulterated products are on the market, and also a number of turpentine substitutes. The latter generally contain spirits of turpentine to which have been added solvent naphtha, petroleum spirit, rectified rosin spirit, and similar products, together with small quantities of certain essential oils, as for instance, phenol oil, anise oil, citronella, etc., etc.

The presence of these additions or adulterants to the solvent can be detected by recognized chemical and physical tests, which are described at length by Lavache and McIntosh in *The Manufacture of Varnishes and Kindred Industries*, Vol. III.

The properties of other good solvents are also included in Table X.

TABLE X

PREPARATION OF SOLVENTS BASED ON FIGURES PUBLISHED BY FLEMING & STEEL IN *World Power*,
MARCH-APRIL, 1924

Name of Solvent.	Origin of Solvent.	Chemical Composition.	Sp. Gr. at 15° C.	Boiling Point at :				
				Atmos. Press.	20" Vac.	24" Vac.	28" Vac.	29.5" Vac.
Methylated Spirits	Obtained by dry distillation of wood, etc.	90% C_2H_5OH 10% CH_3OH	.820-.832	66	65	46.1	23.5	29.5" Vac.
Petroleum Spirit (Benzine)	Distillation of petroleum	Principally Hexane C_6H_{14} & Heptane C_7H_{16}	.725-.760	80	45	35	11	5
Spirits of Turpentine	Distillation of turpentine in water vapour	Principally $C_{10}H_{16}$	.860-.872	160	131	110	87.7	65
Acetone	By distillation of calcium acetate	$CH_3 \cdot CO \cdot CH_3$	.799	56	—	—	—	—

ACETONE. Pure acetone is obtained by rectifying the crude distillate from the dry distillation of acetate of lime (calcium acetate). The general physical properties of acetone are shown in Table X. This solvent is also manufactured from crude wood spirit by a continuous rectification plant designed by E. Barbet, of Paris. Acetone is used as a solvent in the manufacture of certain special varnishes, particularly as a solvent for synthetic resins and the harder natural gums.

Dryers.

The peculiar drying properties of certain oils have already been referred to, but the drying properties of oils can be still further increased by the addition of materials known as dryers, which, on heating with the oil, either act as catalysts or themselves directly liberate oxygen and in this way accelerate drying. In the manufacture of insulating varnishes, however, dryers should, as far as possible, be kept to an absolute minimum—the amount used seldom exceeds 1 per cent by weight—and are usually added as rosinates or linoleates, which are prepared by heating metallic salts with a limited quantity of linseed oil. The metallic salts generally in use in the preparation of dryers include minium (Pb_3O_4), litharge (PbO), lead acetate ($\text{Pb}(\text{CH}_3\text{COO})_2$), manganese dioxide (MnO_2), manganese sulphate (MnSO_4), manganese nitrate ($\text{Mn}(\text{NO}_3)_2$), manganese borate ($\text{Mn}_3(\text{BO}_3)_2$), manganese acetate ($\text{Mn}(\text{CH}_3\text{COO})_2$), manganese oxalate (MnC_2O_4).

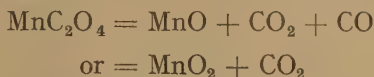
There are objections to the use of all of these materials from an electrical point of view, and these have been enumerated by Alfred R. Matthis as follows—

1. The presence of metallic salts in general.
2. Of these, lead salts will cause clear varnishes to turn black in use by the formation of sulphide of lead.
3. The sulphates and nitrates of manganese, by their decomposition, will liberate sulphuric or nitric acid and render the oils and, therefore, the varnishes acid, whereas the latter should be neutral.
4. Acetate of manganese gives, beside its metallic contribution, a dark colouring to clear varnishes, on account of the tarry impurities of the acetic acids which decompose.

5. Borate of manganese liberates boric acid, a fixed acid which remains in the oil and varnish.

6. The use of manganese resinate is not to be recommended, as preparations containing this product have a strong tendency to polymerize, become sticky, and finally crack.

7. The best of the metallic driers would be oxalate of manganese, as manganese soap is easily formed. Moreover, the oxalate decomposes into carbon dioxide (CO_2) and carbon monoxide (CO), which are given off, leaving in the oil only an oxide of manganese (MnO or MnO_2)



The importance of avoiding the unnecessary use of dryers in insulating varnishes cannot be too strongly emphasized, particularly in view of the steadily increasing demand for quick-drying varnishes in order to enable rapid production of insulated parts.

Manufacture of Varnishes.

The actual manufacture of insulating varnishes is held as a closely guarded secret and calls for the exercising of a considerable amount of judgment and skill. The processes employed are briefly as follows—

OIL VARNISHES. The linseed oil is converted into a quick drying oil or short oil, by a process known as boiling and blowing, which increases its oxygen absorption qualities and brings it to a condition suitable for the addition of gums and other ingredients. If dryers are included, they also are added to the oil at this stage. The copals which are usually employed in oil varnish manufacture are sorted, broken, and placed over an open fire in a special melting pot, in which they are stilled until completely fused. When fusion has taken place, the linseed oil prepared as above is added, and the heating is continued until the gum has been completely dissolved in the added oil. The proportion of gum to oil varies according to the use to which the varnishes are to be put. The gloss and hardness of the varnish when applied depends upon the hardness of the gum used, so that finishing varnishes contain a

considerably larger percentage of gum than those varnishes used for impregnating purposes where the gum content is comparatively small.

After manufacture the varnish is suitably thinned and filtered by passing through special fabric. The varnish should then be clarified by a prolonged storing period, preferably in semi-darkness.

Varnishes containing China wood oil are produced in a similar manner to the above.

ASPHALTUM VARNISHES. The manufacture of asphaltum varnishes is considerably simpler than that of oil varnishes; they are, in most cases, produced in the cold by shaking up the broken asphaltum with a suitable solvent. This process is carried out in specially constructed shaking drums. In certain cases, a process very similar to that employed in the manufacture of oil varnishes is employed, except that steam heating of the melting pots is usually resorted to, in order to minimize the risk of fire during the period of adding solvent to the fused asphaltum. In both of the above processes the varnish is allowed to stand after making, in order that insoluble matter may settle out. The solvents used include turpentine, purified petroleum spirit, and coal tar naphtha. In many cases, linseed oil is also added.

Asphaltum varnishes made in the above outlined manner are very frequently used for japanning work and as black enamels, except that, in the latter case, hard copals are also added in order to give hard and glossy finishes. Where flexibility is desired, soft oleo resins are sometimes incorporated into the varnish.

For impregnation work, asphaltums (native asphalts, residual asphalts, etc.) are frequently employed, more or less in their natural state, but rendered liquid by the application of heavy coal tar oils, mineral wax tailings, etc.

SPIRIT VARNISHES. The most commonly used spirit varnishes in the electrical industry consist of shellac dissolved in methylated spirits with or without the addition of aniline colouring agents. Small quantities of castor oil and copals may be added in order to increase flexibility and durability. The actual process of mixing is extremely simple and consists of

agitating suitable quantities of alcohol solvent (usually methylated spirits) in a barrel with shellac. The varnish is usually mixed to a consistency of about 0.98, and can afterwards be thinned down by the addition of solvent according to requirements.

Spirit varnishes suitable for mica sticking work frequently do not contain shellac, but are made entirely from copals, as for instance, manilla and kauri.

Flexibility is also in this case frequently secured by the addition of castor oil.

Synthetic resin varnishes have been grouped under the heading of spirit varnishes. The manufacture of varnishes of this type calls for the synthetic resin to be supplied in its unbakelized condition, i.e. with its characteristic condensation process only partially complete. The two solvents generally employed in conjunction with one another are acetone and methylated spirits.

PIGMENTED VARNISHES. Since pigmented varnishes merely consist of oil varnishes to which pigments have been added, no further note is required here regarding their manufacture.

The pigment generally employed in the manufacture of the so-called grey insulating enamels and varnishes, which are claimed to have special heat conducting properties, is lithopone. Zinc oxide has also been employed as a filler in making these varnishes, and is claimed to possess the advantage that it will not deposit as a sediment when the varnish is left to stand for any considerable time.

Properties of Insulating Varnishes.

Table XI shows some characteristic properties which may be expected in the various types of insulating varnishes made with oils, already referred to in Table VIII. The figures are all obtained by the methods detailed in Appendix I, except the moisture absorption figure, which was obtained on a sample of pressboard 4 in. square by $\frac{1}{8}$ in. thick. In its unvarnished state, the pressboard in question showed an absorption figure of 145 per cent.

In addition to the properties shown in Table XI, such considerations as elasticity, heat conductivity, and penetration

TABLE XI.—SOME PROPERTIES OF COMMONLY-USED INSULATING VARNISHES

	Drying Hours.		Specific Gravity at 15.5° C.	Redwood Viscosity at 15.5° C.	Electric Strength: Volts/ml.	Moisture Absorption through Varnish on Sample of Pressboard.	
	Oven.	Air.				1 Coat.	2 Coats.
<i>Oil Varnishes</i> — Linseed oil, China wood oil blended with resins, gums, and driers, and thinned with hydrocarbon solvents (petroleum, naphtha, benzene, turpentine substi- tute, etc.)							
1. Baking coil varnish	6		0.855-0.875	30-50	700-900	100.5	42.82 ¹
2. Baking cloth varnish	8		0.830-0.875	30-50	700-900	—	—
<i>Asphaltum Varnishes</i> — Native asphalts dissolved in benzine and frequently blended with linseed and wood oils, thinned with hydrocarbon solvents.							
1. Black plastic varnish	15		0.830-0.860	45-55	900-1200	20.09	1.12
2. Black baking japan	6		0.870	—	600	—	—
<i>Spirit Varnishes</i> — Lacs, gums, and synthetic resins dissolved in de- natured alcohol, acetone, etc.							
1. Black finishing varnish	5-10 min.	$\frac{1}{2}$	0.870-0.930	40-70	600	104.3	44.00
2. Clear finishing varnish		3	0.945-0.955	20-30	500	—	—
3. Mica sticking varnish		2	0.850-0.870	—	—	—	—
4. Shellac as a binder		2	0.975	60-70	900	—	—
5. Hard copal for finishing, etc.		12	0.800-0.900	5-10	500	—	—
6. Synthetic for finishing	2-6	10-30 min.	0.980-1.000	60-80	200	101.3	95.3
7. Synthetic for paper treating	2-6	10-30	0.980	60-65	350	—	—
<i>Pigmented Varnishes</i> — Oil varnishes loaded with lithopone or other pig- ments to improve their thermal and filling characteristics.							
1. Grey enamel	2-3	8-10	1.2-1.4	60-160	450	114.9	93.42

¹ 3 coats show 1.19; 4 coats, 0.94; and 5 coats, 0.42.

must be taken into account in selecting insulating varnishes. Greater elasticity is obtained by a reduction in the amount of hard resins employed. The acidity of insulating varnishes is of importance, since the greening of cotton insulation is frequently attributed to the presence of fatty acids from the varnish.

Methods of Using Insulating Varnishes.

A general classification of the uses of insulating varnishes has already been given in Table XI, but the following remarks on the actual methods employed may be of interest.

1. TREATMENT OF COILS, WINDINGS, ETC. Two general methods are in use for treating coils, windings, and insulated parts generally with oil base insulating varnishes. The older is the "vacuum impregnation" method which, however, is gradually giving place to the second method, usually referred to as "hot dipping." Vacuum impregnating consists of baking the parts to be treated for some hours in vacuum so that all moisture is removed, and then "breaking the vacuum" with the varnish used. This method has the disadvantage that it involves the use of expensive plant and of a slow-drying varnish. Rapid-drying varnishes cannot be used, since there is a tendency in that case for the outer film to oxidize and "skin over," leaving wet varnish underneath, which oxygen cannot reach unless liberated from special dryers in the varnish, which is not desirable. In the "hot dipping" method (which simply consists of baking in an oven until all moisture is driven off and then dipping whilst still hot in vats of varnish), the oxygen is not removed from the interstices of the material under treatment, and even although the outer surface may skin over, this included oxygen is still available for "drying" the wet varnish inside. Experience has clearly shown that, provided the articles dipped hot are left immersed until cool, and until all bubbling has ceased, the impregnation secured is practically as good as with vacuum impregnation and possesses the distinct advantage that it permits quick production, due to simpler plant being involved and the possibility of using quick drying (6 to 8 hours baking) varnishes.

2. FINISHING VARNISHES. Finishing varnishes are very

seldom used as dipping varnishes. They are commonly applied by brush, but much more usually by the use of air sprays. The description of these pieces of apparatus does not come within the scope of this work, but amongst the various types of spraying apparatus available, the Aerograph, the Aeron, the De Vilbis, the Eureka Spraying Machine, the Midland Sprayer, the Aerostyle Pistol Sprayer, and the Paasche Air Brush may be mentioned.

3. MICA STICKING VARNISHES. Mica sticking varnishes are most generally applied by hand brushing, but in the manufacture of micafolium the paper base is allowed to pass a varnishing roller operating in a vat of varnish in much the same manner as that employed in treating paper or cloth.

4. TREATMENT OF CLOTH, PAPER, ETC. Details of the methods employed for this work have been given in Chapter IV.

5. USE OF SYNTHETIC (BAKELITE TYPE) PHENOL-ALDEHYDE VARNISHES. The original processes developed by Dr. Baekeland for heat treating phenol-aldehyde varnishes included baking at 150°C . under a pressure at least greater than the corresponding water vapour pressure. This practice has recently been discontinued by most manufacturers, and "Bakelization" is effected by baking at slightly lower temperatures at atmospheric pressure. The lower baking temperature is naturally desirable where organic materials are incorporated which become damaged at temperatures in excess of 125°C .

6. BAKING OVENS. Considerable advances have been made in the improvement of the ovens used for baking insulating materials and drying varnishes. The modern baking oven should be provided with efficient air circulation, uniform temperature, close temperature control, and efficient temperature recorders. "Through" type ovens, in which the products pass through a carefully-graded temperature cycle at a definite speed, are the most up-to-date practice. Solvent recovery apparatus seldom justifies itself on this work.

Standard Specifications.

Up to date there are no standard British specifications for insulating varnishes, but the tests shown in Appendix I

represent a step made in this direction by the British Electrical and Allied Industries Research Association.

List of Products and Trade Names of Materials Recognized as Insulating Varnishes.

Note.—It is necessary to emphasize the fact that the vast majority of the varnishes on the market are sold under names which agree with those used in the text of Chapter VI, and which completely describe the varnish. Some firms, as for instance, Docker Bros., of Birmingham, supply the whole of their products under such fully descriptive names. The following list only applies to such varnishes as are not entirely described by the name under which they are handled, and therefore does not purport to be a list of all insulating varnishes available.

AJAX. A general trade name applied to a wide range of varnishes of all kinds produced by the Sherwin Wilhams Co., of Cleveland, Ohio.

AMDIVAR. A general trade name for a range of varnishes made by American Di Electrics, Brooklyn, U.S.A.

ARMACELL. A name covering a range of three clear insulating varnishes produced by Griffith Bros. & Co., Ltd., of London.

ARMOVER. A black air-drying insulating varnish made by American Di Electrics, of Brooklyn, U.S.A.

BRITANNIA. Is the registered trade name given by Robert Ingham Clarke & Co., Ltd., to a range of insulating varnishes of all classes, including enamels for covering enamelled wires, etc.

BAKALAQUE. A synthetic resin varnish produced by Attwater & Sons, of Preston.

CABELLAC. A black cable finishing varnish supplied by Pinchin, Johnson & Co.

CELLON. A general term used in Germany and elsewhere to describe varnishes made from cellulose acetate.

CHINALAC. A name used by the John C. Dolph Co., of Newark, N.J., to describe a number of insulating varnishes for various purposes.

COILOVER. A black plastic varnish supplied by American Di Electrics, Brooklyn, U.S.A.

DIELAC. A black finishing varnish supplied by E. Calmon & Co., of New York.

DISCUM. A black coreplate varnish made by Griffiths Bros. & Co., Ltd.

ELO. A synthetic resin varnish made by Birkby, of Liversedge, Yorkshire (see Chapter XIV).

ENDOLAC. A spirit finishing varnish supplied in "black" and "golden" by Pinchin, Johnson & Co.

FORMAPEX. A synthetic resin varnish produced by the Ioco Rubber and Waterproofing Co., Ltd., of Glasgow.

FORMITE. A synthetic resin varnish made by the Damard Lacquer Co.

GLIMALAC. A mica sticking varnish made by Pinchin, Johnson & Co.

INSULAC. A clear finishing varnish supplied by the Robertson Chemical Co., of Cleveland, Ohio.

INSULDERM. A grey insulating enamel "made to supersede the German product known as Electro-enamel." by Griffiths Bros. & Co., Ltd.

KOPAN, ABALAK, JEWELITH. Are synthetic resin varnishes, all manufactured by Dr. Fritz Pollak, Vienna, XXI Fultonstrasse, and used for manufacture of varnish paper products, moulded compositions, synthetic amber goods, etc.

LINOLAC. An amber-coloured insulating varnish supplied by the Micanite Insulator Co., of U.S.A.

MINERVA. A general trade name covering the range of insulating varnishes made by Pinchin, Johnson & Co.

NEPONSET. Shellac clear finishing varnishes by the Robertson Chemical Co., of Cleveland, Ohio.

NUELASTIC. A black plastic varnish supplied by American Di Electrics, of Brooklyn, U.S.A.

OHMALINE. A name covering a range of six black insulating varnishes made by Griffiths Bros. & Co., Ltd., London.

OHMLAC. A trade name for an air-drying black finishing varnish supplied by E. Calmon & Co., New York.

OPELAC. A name applied to both clear and black finishing varnishes by American Di Electrics, Brooklyn, U.S.A.

ORMALAC. A black plastic varnish supplied by Robertson Chemical Co., of Cleveland, Ohio.

PAKYDERM. A quick drying finishing varnish supplied by Griffiths Bros. & Co., Ltd., in both black and golden finish.

P. AND B. COMPOUND. Is a special bitumen base compound made by the Ruberoid Co., Ltd., of Brimsdown, Middlesex.

RESISTOLAC. A black baking varnish supplied by the Robertson Chemical Co., of Cleveland, Ohio.

STANDARD. Is the registered trade name of a number of insulating varnishes made and supplied by Pinchin, Johnson & Co., Ltd., and Standard Varnish Co., of U.S.A.

STIC-LAC. An air-drying clear varnish supplied by E. Calmon & Co., of New York.

STICOLENE. A mica sticking varnish made by Griffiths Bros. & Co., Ltd.

STERLING. Is a trade name given to a complete range of insulating varnishes produced by the Sterling Varnish Co., of Pittsburg, Pa.

VOLTALAC. A black varnish supplied by Pinchin, Johnson & Co., Ltd., and Standard Varnish Co., of U.S.A., for baking or air drying. Elastic Voltalac is a special grade for oil immersed transformer work.

WALPOLE. The Robertson Chemical Co., of Cleveland, Ohio, have a whole series of varnishes on the market designated as "Walpole" varnishes.

CHAPTER VII

PRESSBOARDS

(INCLUDING CELLULITH AND SEMI-COLLOIDAL PRODUCTS
FROM VEGETABLE FIBRES)

PRESSBOARDS constitute a form of insulation the potentialities of which are only commencing to be realized as manufacturers of such materials apply themselves to producing products specially for the electrical industry. In earlier days, the fullerboards, presspahns, and pressboards made for supplying the wool-finishing industry and similar purposes were found good enough for a limited use in the electrical industry. These materials were produced from a variety of raw and waste materials, including wood pulp, waste paper, sacking, ropes, rags, etc. The pressboards now available for electrical work are, as a rule, produced from selected raw materials, and are made under carefully controlled manufacturing conditions to ensure uniformity of texture and electric strength.

The British Electrical and Allied Industries Research Association has given the following definition of pressboard—

The term “pressboard” denotes all materials marketed as pressboard, presspahn, or fullerboard, which materials are made by a paper-making process from vegetable fibres, but differ from papers in that they are made on a “board” machine and are afterwards subjected to great pressure in order to remove excess of water and to “close up” the material, thus producing a solid board. The boards are afterwards dried, and if specified, are glazed by calendering and planishing.

Note.—Strawboard is not included as its use is considered undesirable for electrical purposes.

The E.R.A. has also classified the various kinds of pressboard used in the electrical industry, as follows—

CLASS A. Hard, non-porous, untreated pressboard, having a density not less than 1.15 and not exceeding 1.30 after

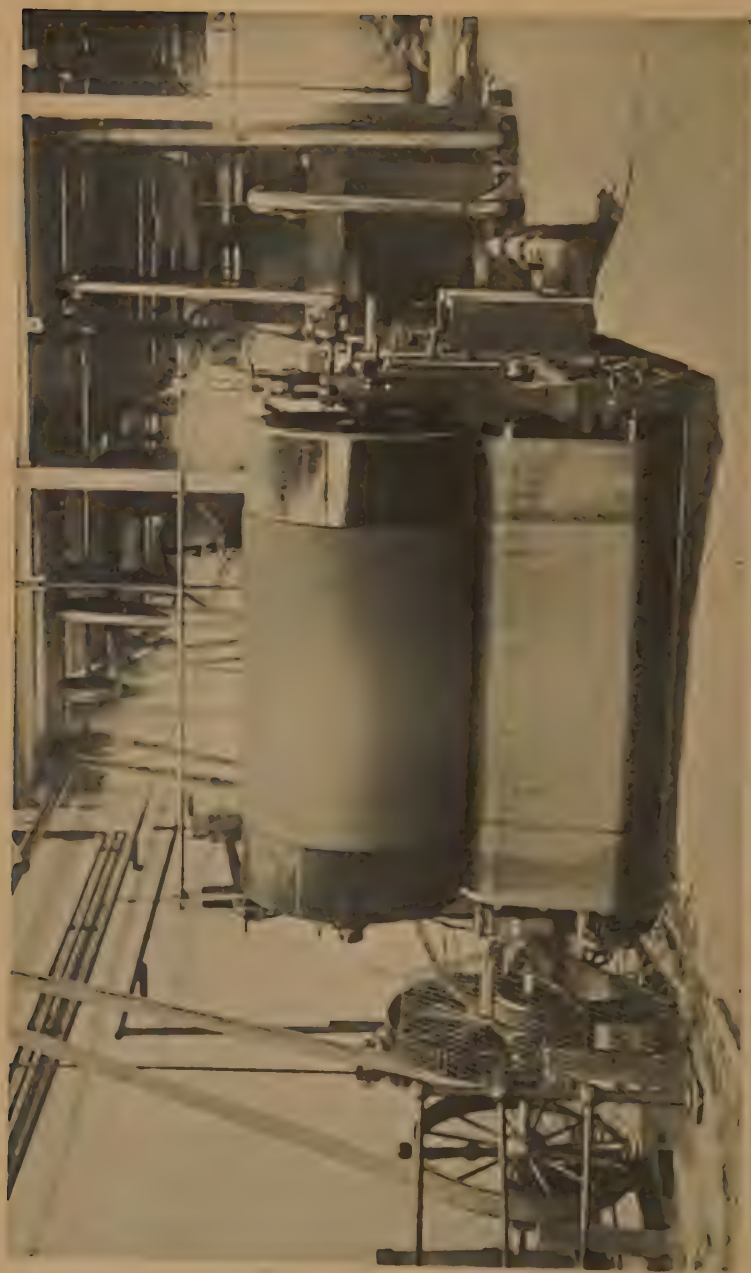


FIG. 8.—A Modern Pressboard Plant

Showing a machine for heat treating in the works of Messrs. F. S. & W. W. Wray, Ltd., Portland, U.K.



FIG. 8A.—Modern Pressboard Plant
Press and drying oven (Messrs. B. S. & W. Whiteley, Ltd.).

18 hours' drying at 80° C., and characterized by a relatively high electric strength.

CLASS B. Soft, untreated pressboard, having a density less than 1.15 but not lower than 0.90 after 18 hours' drying at 80° C, and consequently having a relatively lower electric strength combined with greater absorption than Class A pressboard.

CLASS C. Pressboard impregnated during manufacture with varnish, oil wax, and the like, to improve its electrical properties.

CLASS D. Extra dense, untreated pressboard, having a density exceeding 1.3 after 18 hours' drying at 80° C. and characterized by a higher electric strength than Class A.

CLASS E. Thin pressboard, having a density not less than 1.15 and relatively greater flexibility and high tensile strength after 18 hours' drying at 80° C. (This class of pressboard is specially adapted for slot lining and similar purposes.)

Composition of Pressboards.

In an article contributed to the *Electrician* on 25th November, 1921, by Fleming and Monkhouse, some interesting information was given with regard to the characteristics of pressboards made from various vegetable fibres. Fig. 9 has been prepared from these results, taken in conjunction with later figures which have been supplied by Messrs. B. S. & W. Whiteley, of Pool (Leeds). From these curves, the figures shown in Table XII, the following conclusions may be drawn—

(a) Wood pulp boards when properly dry and free from waxes are too stiff for many purposes and are liable to age rapidly, although their electric strength when dry is good.

(b) Cotton rag pulp boards are soft, porous, show a high electric strength, and are very pliable.

(c) Jute and hemp pulp boards made from old bags, etc., show a high electric strength, but since they are made from highly lignified fibres they become very brittle after prolonged immersion in hot oil.

(d) Linen rag pulp boards are tough, pliable, and show a high electric strength.

Process of Manufacture.

As indicated in the definition of the material, pressboard is produced by a paper-making process and the various operations of alkali boiling, beating, straining, etc., are the same as have already been described in Chapter III dealing with paper making. The board is made on a board machine (see Fig. 8), which differs from a paper-making machine in that it winds up the consecutive layers of pulp (each virtually a layer of

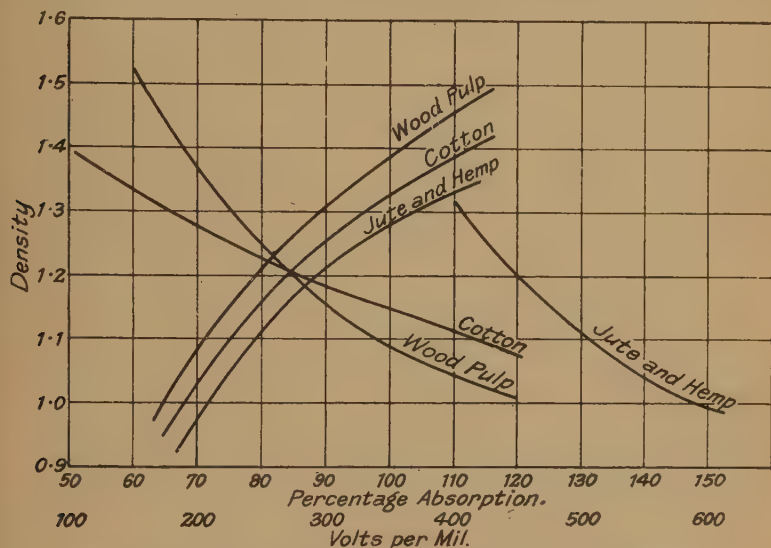


FIG. 9.—Curves Showing Percentage Absorption and Breakdown Voltage per mil for Different Materials at Different Densities

paper) until a thick walled cylinder is produced, which is slit longitudinally and in the subsequent pressing and drying processes is handled as a sheet. During the pressing process the sheets are interleaved with several layers of open woven cloth, which act as mediums for conveying away the water as it is pressed from the sheets. The impression of this cloth is generally noticeable on pressboard unless it has been highly calendered or planished. After pressing, the material still contains about 30 per cent of water, which is expelled by slow drying in through type ovens. When dry the boards are calendered and planished according to requirements.

TABLE XII
PROPERTIES OF VARIOUS CLASSES OF PRESSBOARDS

Class according to E.R.A. suggested classification.	Thickness usually Obtainable.	Specific Gravity.	Tensile Strength Long. Tran. Min. either Direction. lbs./□"	Tearing Strength Double Tear. lbs.	Oil Absorption, 105° C. %	Water Absorption, 20° C. %	Flexibility Minimum Bend.		
							Dry Condition.	After 24 hrs. Air, 105° C.	After 24 hrs. Oil, 115° C.
Class A— (Hard)	$\frac{3}{8}$ "	1.25	6500	2	15	100	$\frac{3}{8}$ "	$\frac{3}{8}$ "	$\frac{1}{8}$ "
	$\frac{1}{2}$ "	1.20	"	4	"	"	$\frac{3}{8}$ "	2"	3"
	$\frac{5}{8}$ "	1.15	"	9	"	"	$\frac{3}{8}$ "	1 $\frac{1}{2}$ "	2 $\frac{1}{2}$ "
Class B— (Soft Absorbent)	$\frac{3}{8}$ "	1.15	5000	1.75	20	150	Flat	$\frac{3}{8}$ "	$\frac{1}{8}$ "
	$\frac{1}{2}$ "	1.10	"	4.0	"	"	$\frac{3}{8}$ "	1"	1 $\frac{1}{2}$ "
	$\frac{5}{8}$ "	0.9	"	8.5	"	"	$\frac{1}{4}$ "	$\frac{3}{8}$ "	1 $\frac{1}{4}$ "
Class C— (Impregnated)	$\frac{3}{8}$ "	1.3	5000	2	—	80	Flat	1"	1"
	$\frac{1}{2}$ "	1.3	"	4	—	"	"	2 $\frac{1}{2}$ "	3"
	$\frac{5}{8}$ "	1.3	"	9	—	"	$\frac{3}{8}$ "	2"	2 $\frac{3}{4}$ "
Class D— (Extra Dense)	$\frac{3}{8}$ "	1.3	6000	3	2.0	70	$\frac{3}{8}$ "	$\frac{1}{2}$ "	1"
	$\frac{1}{2}$ "	1.3	"	6	"	80	$\frac{1}{2}$ "	2 $\frac{1}{2}$ "	3"
	$\frac{5}{8}$ "	1.3	"	10	"	90	$\frac{1}{2}$ "	2"	2 $\frac{3}{4}$ "
Class E— (Slot Lining)	$\frac{3}{8}$ "	1.2	6500	2	15	60	Flat	$\frac{1}{8}$ "	1 $\frac{1}{8}$ "
	$\frac{1}{2}$ "	1.15	"	4	"	"	"	"	"

Electric Strength in volts/mil at 90° C. in air. See Curves (Fig. 10).

Properties of Electrical Pressboards.

Fig. 10 and Table XII show the properties to be expected in the various classes of electrical pressboards recognized by the E.R.A. in their classification. The Class D type material is of singular interest, because it indicates the possibilities of pressboards made from special pulps.

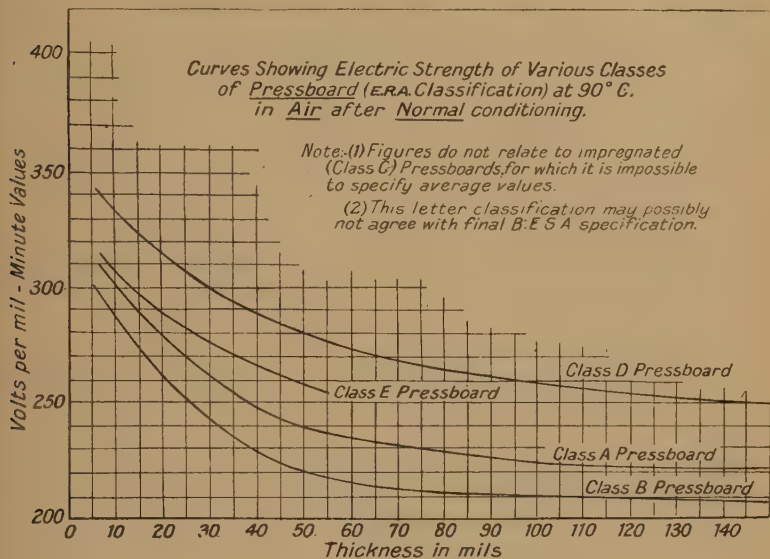


FIG. 10.—Electric Strength of Pressboards.

Cellulith and Semi-colloidal Cellulose Products from Vegetable Fibres.

Closely allied to the Class D material referred to above are a group of materials of which very little indeed is known in electrical work, but which are represented by cellulith. Cellulith is made by carrying on the beating process until complete mechanical hydration is obtained. This takes from 40 to 150 hours in an ordinary beater, depending on the fibre employed. The resultant pulp is virtually a cellulose jelly, which is boiled for two hours to expel the air and then allowed to harden into a solid, horn-like mass. The jelly is also employed as a binding agent for carborundum wheels, etc. It withstands the action of alcohol, ether, petroleum, fats, and oils.

The Plausen Colloid Mill has been claimed to have opened up possibilities in the production of materials of this nature, and Berthold Block, in a paper to a conference of the Vereine Deutscher Chemiker, in September, 1920, described a material which showed an electric strength of 393 volts per mil, and had a specific gravity of 1.20. These figures, however, are comparable with the figures shown under Grade D Pressboard in Table XII, which were obtained on a product known as Elephantide No. 2, produced by Messrs. B. S. & W. Whiteley, Ltd., of Pool (Leeds). Another interesting development in the production of semi-colloidal pulps (known to paper makers as highly hydrated pulps) is the Jackson Beater, which has been the subject of considerable discussion among paper makers of recent years, and may be regarded as a possible solution to the problem of economically reducing vegetable fibres into a very finely beaten state.

Standard Specifications, Etc.

The British Electrical and Allied Industries Research Association has published a report dealing with pressboards (see "Directions for the Study of Pressboards for Electrical Insulating Purposes," *I.E.E. Journal*, Vol. 61, No. 317, p. 486). At the present moment no B.E.S.A. or A.S.T.M. or V.D.E. specifications exist for this material.

List of Products and Trade Names of Materials dealt with in Chapter VII.

ELEPHANTIDE. A name used by B. S. & W. Whiteley, Ltd., of Pool, near Leeds, to cover a range of high-grade insulating pressboards specially made for electrical purposes. Elephantide No. 2 is closely related to Cellulith.

CELLULITH. See description in text of chapter.

CARTON. A French equivalent for pressboards.

SISTOFLEX. A name applied by Spicer Bros. to special grades of electrical pressboards supplied by them.

PRESSPAHN. A German description given to pressboards made from wood pulp. This material is very extensively used by continental manufacturers.

FULLERBOARD is the term frequently employed by British pressboard manufacturers to describe pressboard. These materials were originally produced for the cloth-finishing industry, and hence the term Fullerboard.

CHAPTER VIII

VULCANIZED FIBRE

ALTHOUGH vulcanized fibre has been shown by laboratory tests to be one of the poorest insulating materials in modern use, it has, nevertheless, given most excellent results for many years in a very varied number of applications on low voltage work, including railway joint insulation, fuse holders, slot wedges, packing and spacing blocks, contact carriers on low tension switches, etc., etc.

The general heading, "vulcanized fibre," is here intended to include a large range of similar insulating products made of superimposed layers of high quality paper which have been chemically treated with reagents, capable of changing the surface of the paper into a sticky solution of converted cellulose, so that, when built into boards and tubes, the whole becomes a more or less homogeneous mass with only a trace of the laminae remaining.

Amongst the many materials which come under this definition, the proprietary materials mentioned in the Appendix to this chapter have all found extensive use in electrical insulation work. General terms, such as hard fibre, red fibre, horn fibre, etc., are also in use.

In addition to the above-mentioned electrical fibres, it might be pointed out that other grades of material are produced by fibre manufacturers suitable for the manufacture of trunks, tea-picking baskets, slubbing cans for cotton mills, etc.; but these grades possess no direct interest to electrical manufacturers.

All of the above materials are applicable for certain classes of insulation work, but it should be borne in mind that vulcanized fibre as a whole can only be regarded as an inferior insulation. The V.D.E. rules have definitely specified that vulcanized fibre shall not be used in positions where the working voltage across the material exceeds 15 volts per mil. A recommendation of a similar nature has recently been put forward



FIG. 11.—Electricity Plant of the Dai Nippon Paper Co., Ltd., Yokohama, Japan.
The machines from left to right.

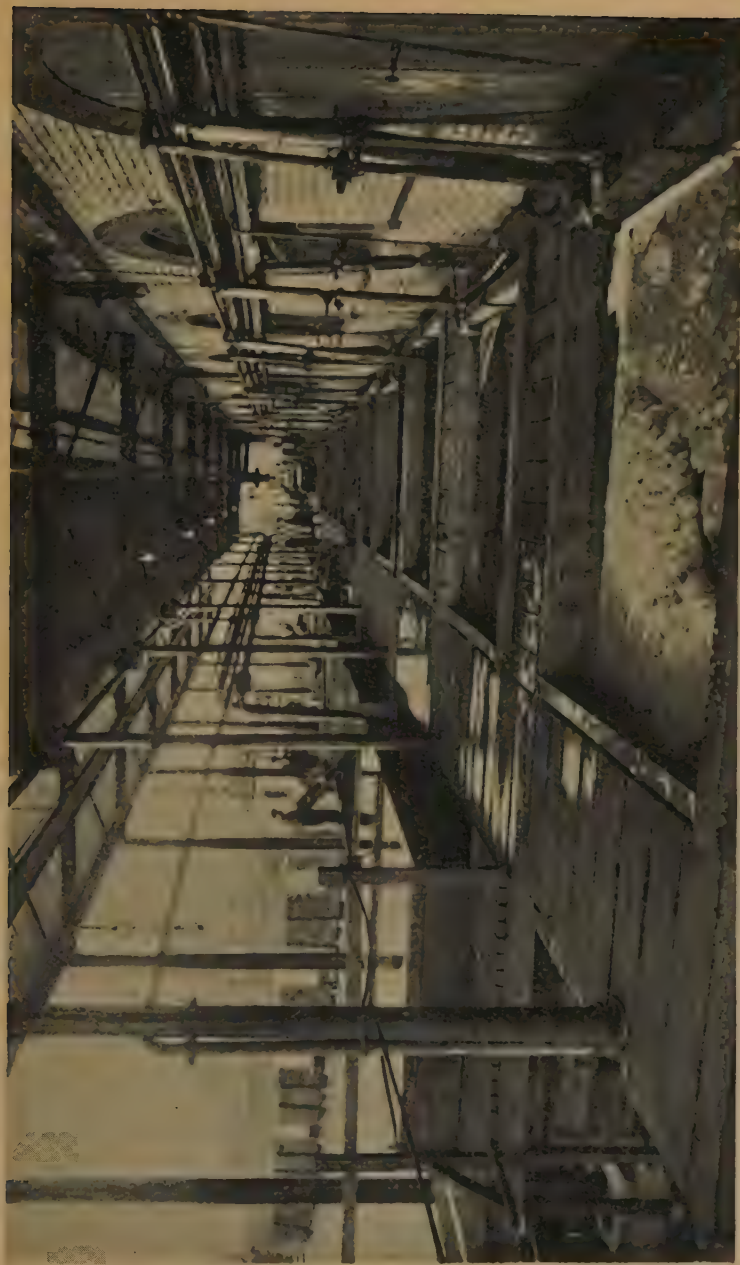


FIG. 11A.—Fibre-making Plant of the Diamond Fibre Co., Ltd., Maidstone, Kent.
The washing tanks.

by the B.E.S.A. limiting its working stress to 20 volts per mil in dry situations.

Materials Employed in the Manufacture of Vulcanized Fibre.

1. PAPER. With the exception of one or two special materials all vulcanized fibre is made from selected cotton rags. Cotton is chosen for this work, since, as has already been shown (Chaps. IV and V), it is the purest form in which cellulose occurs in nature. In its natural state, the cotton fibre is coated with a wax, which is not easily entirely removed. Since the presence of this wax will prevent the chemical reagents employed in the manufacture of vulcanized fibre from reaching the cellulose and converting it to a jelly, all fatty matter must be removed before the paper is made into fibre. Experience has shown that the most economical method of ensuring that no wax is present, is to employ nothing but well-worn (and consequently frequently-washed) cotton rags.

The paper employed is, generally speaking, in the neighbourhood of from 5 to 7 mils in thickness, and only moderately dense.

In the manufacture of flexible slot-lining material, which has been sold under the name of horn fibre, analysis has shown that the raw fibre employed consists very largely of jute. This, however, should be looked upon entirely as an exceptional material for special purposes. It is generally understood that the paper for manufacturing vulcanized fibre should be made from cotton only, and many buyers include this proviso in their purchasing specifications.

2. CHEMICAL REAGENTS ("ACIDS"). Amongst many chemical reagents which are capable of dissolving cellulose and converting the same into celluvert, the following have been commercially applied: zinc chloride, cupra-ammonium nitrate, calcium chloride thiocyanate.

The first mentioned of these is the chemical almost universally used in the manufacture of vulcanized fibre. Cupra-ammonium nitrate has, however, been utilized, although its present application is chiefly in the manufacture of waterproof canvases, etc., known under the name of Willesden goods.

The use of the last-named reagent—calcium chloride thiocyanate—is probably capable of considerable development, particularly as its use very largely obviates the necessity of the long washing treatment which is inevitably associated with fibre produced with zinc chloride.

Zinc chloride is itself slightly alkaline, but, nevertheless, is generally referred to in the fibre-making industry as the “acid,” and is used at a temperature of $40^{\circ}\text{C}.$, with a specific gravity of approximately 1.8. It is probably this misuse of the word “acid” which has resulted in many users of vulcanized fibre applying a test for acid when, as a matter of fact, almost without exception, vulcanized fibre is slightly alkaline.

3. COLOURING MATTER. It is strongly to be recommended that vulcanized fibre for electrical purposes should be entirely free from colouring matter, i.e. should be what is known in the trade as “natural coloured.” Although vulcanized fibre can be given various colours by the use of non-injurious dyes, or by the inclusion in the paper from which it is made of fast dye cotton rags (as for instance, Italian linings, etc.), it is, nevertheless, very common practice amongst fibre makers to colour their material with red iron oxides, bone ash, etc. These latter materials, particularly the iron oxides, are not infrequently introduced in very considerable quantities, thus giving additional weight to the product, but at the same time, as tests have conclusively shown, seriously deteriorating both the electrical and mechanical properties of the material.

Certain grey materials, such as leatheroid, owe their colour to the inclusion of 10 per cent to 15 per cent of fast-dyed black rags in the paper from which it is made. In such a case as this, the colouring in no way deteriorates the material.

Process of Manufacture.

The process of manufacturing vulcanized fibre consists in passing the paper through a bath of zinc chloride solution maintained, as already stated, at approximately $40^{\circ}\text{C}.$ and 1.8 specific gravity, after which it is wound on to a large heated drum until the desired thickness of treated paper is built up. The resulting cylinder of treated paper is then slit parallel to its axis, so that the built up material can be peeled

off the drum in the form of a flat sheet. At this stage, the material is exceedingly soft and pliable, and considerable care is required in handling it. These sheets are then subjected to immersion in solutions of zinc chloride, diminishing in strength from specific gravity of 1.75 downwards, until finally they are washed in pure water. This process of washing is necessarily an extremely long one, since it is necessary to avoid the zinc chloride in the material becoming hydrolized and forming zinc hydroxide and zinc oxychloride. Should such chemical action take place, the generation of zinc hydroxide results in the formation of blisters, which are usually relieved by pricking. Vulcanized fibre sheets showing evidence of being pricked in this manner are to be viewed with suspicion by electrical manufacturers, since the presence of evidences of pricking indicates that the process of washing has probably been unduly hurried.

In the manufacture of good quality fibre, the time occupied in washing may vary from eight months in the case of 1 in. sheets to six days in the case of the thinnest materials.

After removal from the washing tanks, the fibre is allowed to dry at a temperature of 40–60° C. for a period of many weeks. Investigations would appear to indicate that here, again, a long, slow drying period results in the production of the highest quality materials. During this drying period, the fibre sheets shrink approximately 10 per cent in size.

It has been noticeable that, during the years which have followed the war, the quality of vulcanized fibre generally obtainable on the market has been extremely poor, and this inferiority is very largely to be attributed to hurrying the material in its washing stage and to insufficient time being allowed for drying and maturing.

In the production of fibre tubes, the same general process is adopted. Fibre rods are produced by turning up square bars sawn from sheet material. It is worthy of mention that fibre rods are very frequently produced from the sound portions of sheets which have proved partially defective during manufacture. This fact probably largely accounts for the difficulty electrical manufacturers experience in procuring reliable supplies of fibre rod. Generally speaking, fibre, like any other

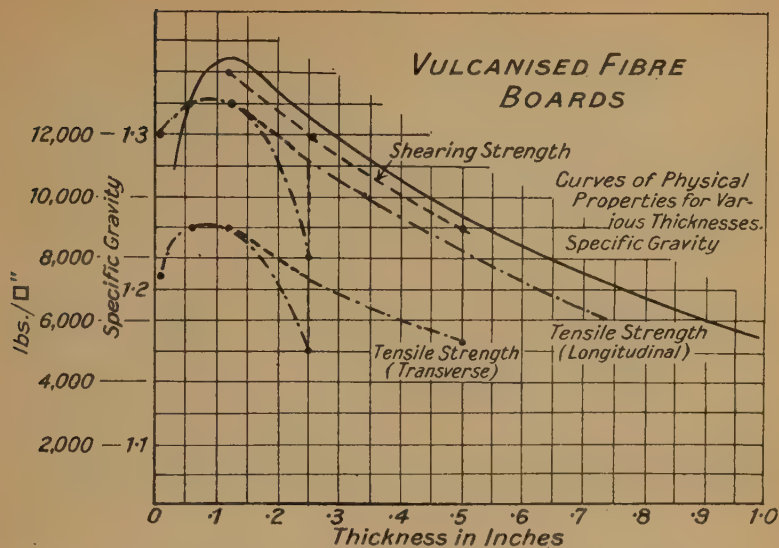


FIG. 12.—Mechanical Characteristics of Vulcanized Fibre for Electrical Work.

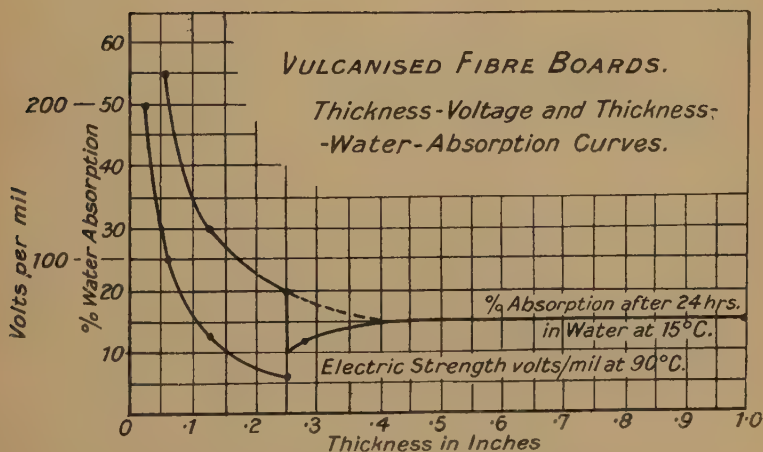


FIG. 13.—Characteristics of Fibre Boards. -

laminated paper product, should not be utilized in rod form, if it is in any way possible to substitute tube material, since there is a natural tendency in the rod to split along the laminae, which of course is not present to the same extent in a tube where the laminae are concentric.

A number of makes of vulcanized fibre, notably leatheroid, fish paper, etc., are supplied in continuous rolls.

This material is manufactured by a continuous process involving the use of exceedingly expensive machinery, in which the vulcanized fibre product is built up by feeding in the requisite number of layers of zinc chloride, treated paper from separate feed rollers. After the component layers have been squeezed into contact between pressed rollers, the material passes in a continuous length, first through a series of vats

TABLE XIII
GENERAL PROPERTIES OF VULCANIZED FIBRE FOR ELECTRICAL PURPOSES

	Sp. Gr.	Tensile Strength: Lbs. per sq. inch.		Shear- ing Strength	Water Ab- sorp- tion. %	Flexibility of Board. Minimum Radius of Bend.		
		Longi- tudinal.	Trans- verse.			Normal Condi- tion.	After Baking.	
<i>Boards—</i>								
Up to $\frac{1}{16}$ " thickness	I·25	11,000	8,000	—	50	$\frac{1}{8}$ "	1"	For electric strength tests, see curve Fig. XIII
$\frac{1}{16}$ "- $\frac{1}{8}$ " "	I·35	13,000	9,000	14,000	25	$\frac{3}{4}$ "	2½"	
$\frac{1}{8}$ "- $\frac{1}{4}$ " "	I·30	8,000	5,000	12,000	15	For thin sheets up to		
$\frac{1}{4}$ "- $\frac{1}{2}$ " "	I·25	9,500	6,500	9,000	10	$\frac{3}{32}$ " figures should be—		
$\frac{1}{2}$ "- $\frac{3}{4}$ " "	I·20	—	—	—	13	$\frac{1}{16}$ "	$\frac{3}{8}$ "	
$\frac{3}{4}$ " & above "	I·15	—	—	—	15			
<i>Rods—</i>								
Up to $\frac{1}{4}$ " diameter	I·25	—	—	—	15	—	—	
$\frac{1}{4}$ "- $\frac{1}{2}$ " "	I·20	—	—	—	20	—	—	
$\frac{1}{2}$ "- $\frac{3}{4}$ " "	I·15	—	—	—	20	—	—	
$\frac{3}{4}$ "-1" "	I·15	—	—	—	20	—	—	
<i>Tubes—</i>								
Up to $\frac{1}{16}$ " wall thick	I·25	—	—	—	50	—	—	
$\frac{1}{16}$ "- $\frac{1}{8}$ " "	I·35	—	—	—	25	—	—	
$\frac{1}{8}$ "- $\frac{1}{4}$ " "	I·30	—	—	—	15	—	—	
$\frac{1}{4}$ "- $\frac{1}{2}$ " "	I·25	—	—	—	10	—	—	

Shrinkage on Boards. Longitudinal, 1% ; Transverse, 2% up to $\frac{1}{16}$ " thickness. Above this the figures should be 0·8 and 1·5 respectively.

in which the washing process is completed, and finally through rapid drying and maturing ovens. Thin vulcanized fibre materials made in this way are found to be inferior in quality to thin sheet materials produced by the so-called "hand-made" process, in which greater times can be permitted for washing, drying, and maturing.

Properties of Vulcanized Fibres.

Table XIII and curves Figs. 12 and 13 indicate the general properties which are to be expected in a good grade of vulcanized fibre. It should be noted that the sharp irregularities in the curves for materials approximately 0.25 in. in thickness are due to the fact that at this thickness manufacturers, as a rule, change the thickness of the paper employed.

Standard Specification.

A standard specification for vulcanized fibre is in preparation by the British Engineering Standards Association. The E.R.A. has published preliminary data on this material (see *I.E.E. Journal*, Vol. 61, No. 322, September, 1923). The V.D.E. rules also specify limiting values for this material.

List of Products and Trade Names of Materials dealt with as Vulcanized Fibre.

EGYPTIAN FIBRE. A registered trade name for a high quality natural coloured fibre made by the Delaware Hard Fibre Co., Wilmington, Del., U.S.A.

PEERLESS (LEATHEROID) INSULATION. A thin vulcanized fibre usually in rolls made by the Delaware Hard Fibre Co., of U.S.A.

DISFICO. A thin vulcanized fibre made by the Diamond State Fibre Co. of America.

DELAWARE INSULATION. A thin vulcanized fibre made by the Delaware Hard Fibre Co., Wilmington, U.S.A.

AMALITH. A special grade of vulcanized fibre produced in the U.S.A.

FISH PAPER. A general term used largely in America for thin (usually grey) vulcanized fibre. Synonymous with leather paper.

HORN FIBRE. Two products are described as horn fibre—one a special fibre produced by the Diamond Fibre Co., of U.S.A., for slot lining purposes; the other use of the word is to describe any particularly hard fibre with a horny substance.

FIBEROID. A vulcanized fibre produced in U.S.A.

LEATHEROID AND LEATHER-PAPER. A general term for thin vulcanized fibre supplied in grey colour. (See text.)

WHALL'S FIBRE. A special grade of vulcanized fibre, first produced by Mr. C. H. Whall for railway track signalling work and supplied by C. H. Whall & Co., of Boston, U.S.A.

WILLESDEN PAPER. A thick paper treated by the Willesden (cupro-ammonium nitrate) process by the Willesden Paper and Canvas Works, Ltd., and used in place of thin vulcanized fibre on field magnets, as slot lining, etc.

WHALEBONE FIBRE. A trade name employed by the Diamond State Fibre Co., of U.S.A., to describe a high quality natural-coloured fibre.

SUPER-SEASONED FIBRE. A grade of vulcanized fibre specially made by the National Fibre Co., of U.S.A., for electrical work, and sold in England by J. Burns, Ltd., of Chadwell Heath, Essex.

CHAPTER IX

LAMINATED VARNISH PAPER (AND VARNISH FABRIC) PRODUCTS

THE rapid development of transformer and E.H.T. switchgear work which has characterized the last few years has been responsible for a corresponding increase in the use of laminated varnish paper products. Under the heading "Varnish Paper and Varnish Paper Products," a wide range of material is covered, in which laminae of paper, vulcanized fibre, organic fabrics, and inorganic fabrics are cemented together to form boards, tubes, or cylinders. It is convenient to group these materials according to the cementing medium employed. The following cements or bonds are in general use—

- (a) Synthetic varnish bonds. (So-called "Bakelite" products.)
- (b) Natural resin and gum bonds. (Chiefly shellac.)
- (c) Asphaltum bonds.

Synthetic Varnish Products.

Synthetic varnish bonded products have been graded by the E.R.A. as described below—

GRADE A. This includes synthetic resin varnish paper (fabric) boards (tubes), the principal characteristics of which are low water absorption, high resistivity, and good machining properties. This class of material does not necessarily possess a high electric strength at high temperatures, and is generally used for radio work and electrical apparatus where the dielectric is not subjected to a high electric stress at a high temperature.

GRADE B. This includes synthetic resin varnish paper (fabric) boards (tubes), the principal characteristic of which is a high electric strength at high temperatures. This grade, in general, has not as good machining properties as Grade A, and is generally used in electrical machinery where high electric strength is required at a high temperature, as, for example, in oil immersed plant.

GRADE C. This includes synthetic resin varnish paper

(fabric) boards (tubes), made from an inorganic paper or fabric (such as asbestos). The principal characteristics of this material are its ability to withstand high temperatures without serious loss of mechanical properties. This grade, in general, has not as high an electric strength as either Grade A or Grade B, is more hygroscopic, and of lower resistivity. Its machining properties, although sufficiently good to permit of its being drilled, sawn, etc., are not, in general, as good as those of Grade A or Grade B.

Natural Resin and Shellac Varnish Products.

Natural resin and gum bonded products have been graded by the E.R.A. as follows—

GRADE A. This includes natural gum or resin varnish paper (fabric) boards (tubes), possessing relatively high electric strength and able to withstand temperatures up to 95° C. without softening. This material is generally used for transformer insulation.

GRADE B. This includes natural gum or resin varnish paper (fabric) boards (tubes), possessing relatively high electric strength and able to withstand temperatures up to 70° C. without softening. This material is generally used where the temperature rise is small.

Asphaltum Varnish Products.

Asphaltum bonded products have not been classified by the E.R.A., as their use is not general, but restricted to certain special applications.

Process of Manufacture.

The majority of varnish paper products are built up from specially selected paper which has been previously coated with the bonding varnish employed. The chief reason for this practice is that it is found necessary to remove entirely all traces of solvents before the varnished paper is built into a board or tube. This could not be satisfactorily accomplished in a process where the paper is coated and built up into a varnish paper product in one continuous operation, unless solvents were entirely eliminated from the process. Although such processes, in which the bond is introduced in the form of

a finely divided powder sprinkled on to the paper as it passes over heating elements into the machine in which it is formed into a tube or cylinder, have been tried out and are in actual operation, they have not been, however, generally adopted. The usual method is, as already stated, to coat the paper in a preliminary operation, either by passing it through a varnishing machine in which the varnish is applied by a roller operating in a vat, or by rolling the varnish on to a paper as a paste, in the same way that rubber is applied to a fabric in rubber proofing. In either case, great precautions have to be taken to ensure that the treated paper is not over-baked whilst being dried, but, at the same time, the baking process must be sufficient to drive off all solvents and other readily volatile substances. Over-baking of the varnish in these preliminary operations prevents the bond from softening sufficiently readily in the subsequent tube or board building process. This is particularly true of synthetic varnish products. Insufficient removal of the solvent from the treated paper results in the volatile matter being driven off during the subsequent baking process at a time when it is difficult to remove the gases produced from between the laminae, with the result that blisters are frequently formed.

In building the treated paper into boards, it is generally considered good practice to ensure that the alternate layers are built with the machine direction of the papers at right angles to each other. This ensures that the boards have uniform mechanical properties in both directions.

The pressure employed in pressing up boards is an important factor and may range as high as 1 ton per sq. in. The temperature during this pressing operation is determined by the characteristics of the bond being used, but, in the case of synthetic varnishes, it must be sufficiently high, and be held (under pressure) sufficiently long to ensure the complete change of the bond into its final condensation stage (i.e. complete bakelisation).

In the manufacture of tubes and cylinders, the treated paper is built up on heated mandrels, either by ironing it on to the mandrel with specially constructed heated irons, or by rolling in a three-roller machine with heated rollers. The

paper in each case is fed into the machine under tension, and the compactness of the finished tube is largely dependent on the exact conditions of tension in the paper and the heat and pressure of the irons or rollers being maintained. In certain products, the tubes thus formed are subjected to a further pressing operation in special cylindrical moulds before their removal from the mandrel. This pressing process is also employed in insulating bars and conductors on which the varnish paper covering is to remain permanently (e.g. switch and controller bars, etc.). Obviously, in the manufacture of tubes and cylinders, where the additional pressing process is not employed, the time and temperature used in the building or winding process is not sufficient to mature the bond or bring a synthetic varnish bond into this final condensation stage. In such cases it is therefore necessary, before removal from the mandrel, to bake the product for many hours further at the highest temperature the organic matter contained in it will withstand without deteriorating. Originally, this baking was done under an air pressure of approximately 150 lb. to the square inch, and at a temperature in the neighbourhood of 140 to 150° C. The recent practice favours baking at a very much lower temperature and for long periods, even ranging to several days, since by this means the papers and fabrics employed do not suffer the same damage as when subjected to temperatures as high as 140° C. and upwards.

Square tubes, channels, and similar products are produced from cylindrical tubes by forming them on special mandrels whilst still in their plastic stage before final baking.

Physical Properties.

Table XIV shows the physical properties which may be expected in any of the various grades of varnish paper products.

The water absorption figure shown is that obtained with ordinary commercial products, and it is necessary to point out that despite the claims of various manufacturers, all materials which contain unconverted cellulose, vegetable fibres, etc., in their construction are inherently hygroscopic. The absorption values for Grade A synthetic varnish paper materials are extremely good when taken in comparison with figures obtained

TABLE XIV
CHARACTERISTIC PROPERTIES OF VARIOUS GRADES OF VARNISH-PAPER AND VARNISH-FABRIC PRODUCTS

Class	Grade.	Thickness.	Sp. Gr.	Tensile Strength : Lb. per square inch.	Compression Strength: Lb. per sq. in. at 20° C.	Shearing Strength: Lb. per sq. in.	Impact Strength: Foot-lb.	Softening Point:	Water Absorption, %	Electric Strength: Min. Val. at 90° C. in Air. Volts/mil.
Synthetic Varnish Boards.	A Varnish paper only	$\frac{1}{8}$ " $\frac{1}{4}$ " $\frac{1}{2}$ "	1.35	8,000 to 14,000		9,000	0.25 to 4.00	110° C. to 150° C.	1.00 to 0.75 to 0.50	See Curves Fig. 14
	B Varnish Paper only	$\frac{1}{8}$ " $\frac{1}{4}$ " $\frac{1}{2}$ "	1.32	10,000 to 17,000	15,000	13,000 to 12,000 to 11,000	1.25 to 4.50 to 10.00	110° C. to 160° C.	2.00 to 1.50 to 1.00	
	A Varnish Fabric Duckcloth	Various thicknesses		8,300 to 9,500						
	Bakelite Asbestos	Various thicknesses	1.40	8,000 to 8,500	Across the grain 25,000 to 30,000					
Synthetic Varnish Tubes	A	Int. Ext. Diameter: 1" 1½" 2" 3"	1.30	8,500 —	13,000	—	—	110° C. to 150° C.	.5 to 1.0 to .75	See Curves Fig. 15
	B	1" 2" 3"	2.36	8,750 —	11,000 to 10,000 to 12,000	—	—	110° C. to 150° C.	4.00 to 7.00 to *3.75	
Shellac Paper Boards	A							75° C. to 95° C.	6	
Shellac Paper Tubes.	A					—	—	75° C. to 95° C.	8	

* For large cylinders, this value may be as high as 4.2 even for good quality varnish-paper products.

on any other fibrous dielectrics, but, nevertheless, they are not sufficiently good to allow this material to be regarded as non-hygroscopic (and compared with porcelain, etc., in this respect), unless suitably protected with a sound, good, and impervious varnish coating. The following are comparative water absorption figures taken after 24 hours' immersion at 20° C. for various fibrous dielectrics. Bakelite paper boards, 1.58 per cent; Bakelite paper tubes, 3.95 per cent; Bakelite paper cylinders, 4.20 per cent; vulcanized fibre, 25 to 42 per cent; dense pressboard, 32 to 60 per cent; soft pressboard, 85 to 108 per cent; shellac paper boards, 6 per cent; shellac paper tubes, 8 per cent.

As might be expected, water absorption is dependent upon the pressure employed in making the material. Dr. Retzow, in an article in *Kunststoffe*, 1st April, 1922, showed that water absorption tests on specially made high grade Bakelite paper boards gave the following results. These figures are considerably better than may be expected under commercial manufacturing conditions—

TREATMENT.	Manufacturing Pressure.		
	75 kg.	180 kg.	300 kg.
3 hours in water	1.0	0.7	0.5
24 „ „	2.6	2.0	1.6
96 „ „	3.4	4.7	2.8

Dr. Retzow also showed the influence of thickness of sheets in the following results of tests—

TREATMENT.	Thickness of Sheets in mm.			
	1.26	2.37	2.75	4.05
3 hours in water	1.4	1.0	0.6	0.4
24 „ „	4.5	2.0	2.1	1.1
96 „ „	6.0	3.7	3.4	1.5

Note.—External changes in the above sheets could not be seen after a 3 to 24 hours' soaking in water. The increase in

weight was found after very careful drying out and 2 hours' exposure to the air; it was culculated as a percentage of the original weight of each sheet.

Electric Strength.

The curves in Figs. 14, 15, and 16 are given to show what may be regarded as average values for electric strength for synthetic varnish paper products obtainable on the market.

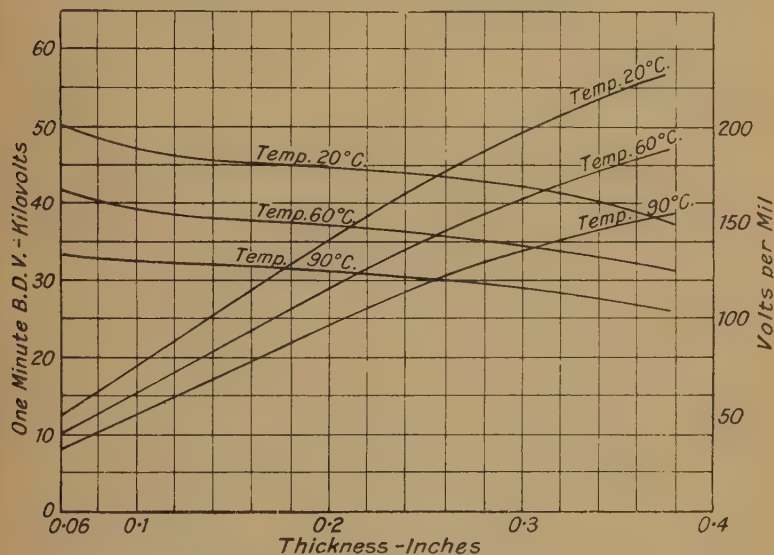


FIG. 14.—Bakelite Paper Boards
Electric Strength Tests in oil

These curves are based upon a mass of information collected from various sources, and include tests made on 29 different grades of material supplied by 19 firms. It should be noted that synthetic varnish paper boards have a very much lower electric strength than tubes and cylinders made from the same material. This is presumably traceable to the difficulty in removing moisture and gases from Bakelite sheets whilst being pressed up. In the case of tubes and cylinders, these gases are very largely driven off during the pre-heating stage through which the treated paper passes immediately before it enters the tube or cylinder. It may also be noted that all

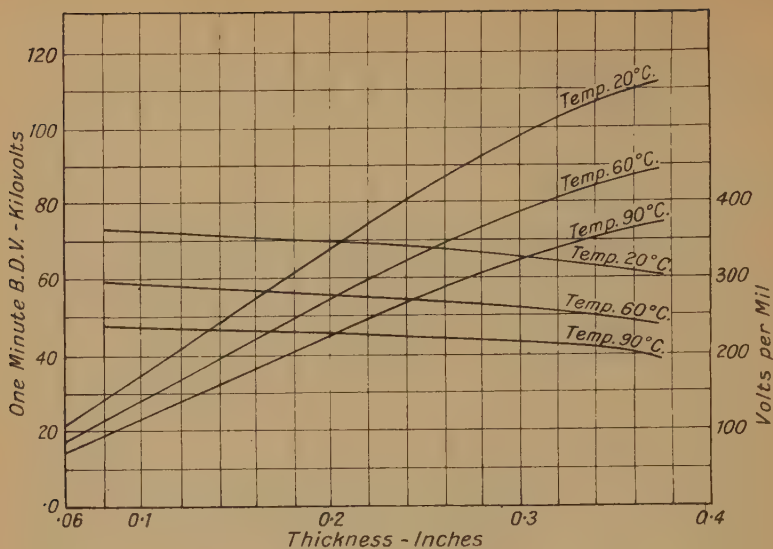


FIG. 15.—Bakelite Paper Tubes.
Electric Strength Tests in oil.

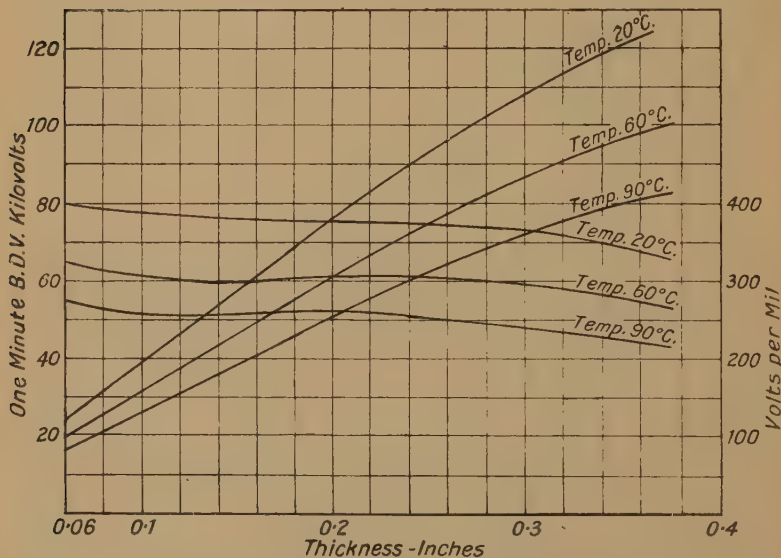


FIG. 16.—Bakelite Paper Cylinders.
Electric Strength Tests in oil.

synthetic varnish paper products appear to have a bad negative temperature coefficient.

Permittivity and Power Factor at Radio Frequencies on Synthetic Varnish Paper Products.

In view of the use of these materials from a large number of radio applications, which work has recently been done by the American Bureau of Standards and also by the E.R.A. to determine the permittivity and the power factor of laminated synthetic resin products at radio frequencies, the method employed in both cases is that which has been laid down by the American Society of Testing Materials in their Specification Nos. D150-22T, and it is pleasing to note that the results obtained in both sets of tests agree extremely closely.

PERMITTIVITY. (*Specific Inductive Capacity or Dielectric Constant.*) The Bureau of Standards Report No. 216 shows the dielectric constant for various grades of American synthetic varnish paper products as varying between 5.2 and 5.9. The Westinghouse Electric and Manufacturing Co.'s material 21D, which is a specially tough product made with duckcloth instead of paper, showed a figure of 6.4, and Formica Insulation Co.'s similar product showed 6.5. The Condensite Celleron Products, which use thin vulcanized fibre as a base, showed a dielectric constant of 6.6 and 6.8. The Bureau of Standards tests were made with wave lengths 600 to 4,800 metres.

Tests recently published by the E.R.A. on 19 different materials, including both boards and tubes, have given results confirming closely those quoted above.

The E.R.A. tests may be summarized as follows—

Description of Material.	Condition of Test.	Permittivity at Wave Lengths. (Metres).				
		300	600	1,500	3,000	5,000
Boards	1. Normal	5.6	5.7	6.0	6.2	6.3
	2. At 60° C.	5.2	5.2	5.4	5.5	5.5
	3. After 24 hr. in water at 20° C. }	5.7	5.9	6.1	6.4	6.6
Tubes	1. Normal	4.3	4.2	4.4	4.5	4.5
	2. At 60° C.	4.5	4.6	4.7	4.8	4.8
	3. After 24 hr. in water at 20° C. }	4.5	4.6	4.8	4.9	5.0

POWER FACTOR (OR PHASE ANGLE). Tests made by both the above-named authorities to determine the power factor of these particular products also agree very closely, and the E.R.A. results in this case may also be summarized as follows—

Description of Material.	Condition of Test.	Power Factor at Wave-lengths. (Metres.)				
		300	600	1,500	3,000	5,000
Boards	Normal	5.7	5.7	5.7	6.0	6.6
	At 60° C.	4.8	4.5	4.7	5.0	5.7
	After 24 hr. in water at 20° C.	9.4	9.7	11.2	12.3	9.2
Tubes	Ditto	4.4	4.0	3.4	3.0	3.1
		3.8	3.8	3.9	4.3	5.1
		9.0	9.1	9.9	11.5	9.9

Permittivity and Power Factor at Power Frequencies of Synthetic Varnish Paper Products.

It is considered necessary to mention that permittivity and power factor at power frequencies under a separate heading to that in which these quantities are dealt with at radio frequencies, since experience has shown that the values under the two conditions are not necessarily comparable, especially at the higher temperatures met with in power plant apparatus. There is hardly sufficient information available on this point to lay down any definite values, but it is sufficient to say that power factor values may vary between values comparable with those given above and values nearly ten times as great, depending on the conditions of the materials, frequency, and temperature at which the tests are made.

Effect of Arc on Synthetic Varnish Paper Products.

One of the most serious shortcomings of phenol-aldehyde condensation products to which Bakelite and the majority of synthetic resins belong is the inability of these materials to withstand even one exposure to an electric arc without the path of the arc becoming a conducting path. This phenomenon is commonly referred to as "tracking," and has been attributed



BAKELITE PAPER BOARD - 1 TEST.



SHELLAC PAPER BOARD - 10 TESTS.



HARD PRESSBOARD - 10 TESTS.



LINSEED OIL IMPREGNATED WOOD - 10 TESTS.



MICANITE - 3 TESTS.



VULCANISED FIBRE - 10 TESTS.

FIG. 17.—Specimens showing "Tracking" Characteristics of various Insulating Materials.

to the difference in chemical composition of shellac and other adhesive bonds as compared to phenol-aldehyde resins.

Shellac products liberate considerably greater quantities of gas and vapours when exposed to an electric arc than is the case with phenol-aldehyde products, with the result that these gases are frequently liberated with explosive violence, throwing out decomposition products as well as spreading and dissipating the discharge. It has also been shown that the carbonized surface produced by an arc on synthetic resin varnish material is cokey, whereas that produced by exposure to an arc on a material built with the same paper, but using shellac bond, is left with a light, flaky carbon path upon it.

For the above reason, the use of synthetic resin varnish bonded products is strongly to be discouraged wherever they are likely to come into contact with any form of electric discharge. For high tension work where discharge is likely to occur, shellac bond is preferable to Bakelite unless the latter is very carefully protected from actual contact with the discharge. For this reason many manufacturers employ shellac bond when making high tension terminals, bushings, etc. Fig. 17 shows a photograph of samples of various insulating materials which have been subjected to the fuse wire test (see Appendix I). It will be seen that the phenol-aldehyde material has failed after one exposure and begun to "track" or conduct.

Maximum Safe Working Temperature for Synthetic Varnish Paper Products.

Extraordinary claims have been made in the past for certain varnish paper products (particularly synthetic resins of the Bakelite class) as insulators capable of withstanding temperatures up to 150° C.

Whilst it is true that some of the bonding materials are capable of withstanding such temperatures, it is quite wrong to expect any products containing vegetable fibres in the form of papers or fabrics to be capable of withstanding temperature more than is specified for Class A insulation, i.e. a maximum temperature of 105° C.

Synthetic varnish used as a bond with either asbestos paper

or asbestos fabrics is to be regarded as a Class B insulation and may safely be used up to 150°C .

Shellac Paper Products.

Varnish paper products made with a shellac varnish bond do not differ very greatly in their properties from Bakelite paper products up to a working temperature of 60°C . Above this temperature, shellac varnish paper products are liable to soften unless specially cured by being subjected to continued baking at a temperature of 115 to 120°C . for long periods. Shellac paper products (as has already been stated) are, however, not subject to tracking, for which reason they are not infrequently employed in place of Bakelite paper products in positions where an arc may reach them.

Its softening at temperatures over 70° or 80°C . renders shellac varnish an unsuitable bond for use in making laminated boards with asbestos fibre for high temperature work.

General Uses of Varnish Paper Products.

Varnish paper boards are extensively used for a great number of purposes, including terminal boards, barriers in

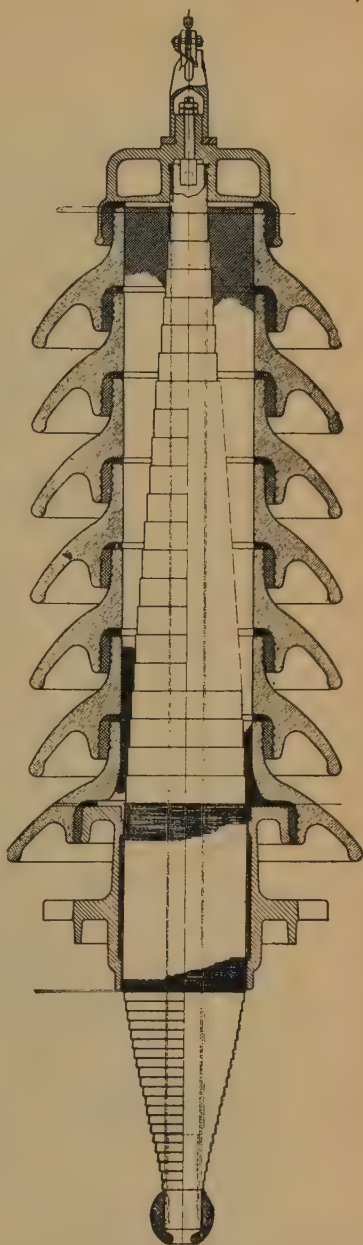


FIG. 18.—Condenser Type Bushing by Metropolitan-Vickers Elec. Co., Ltd.

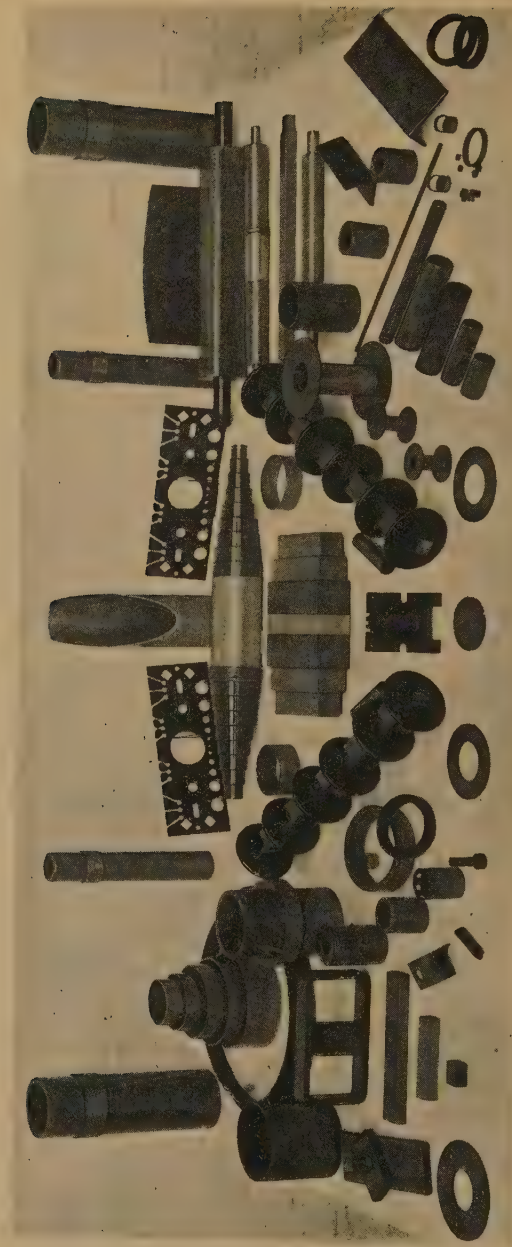


FIG. 19.—A Group of Varnish Paper Products
Made by the Micanite and Insulator Co., Ltd. London.

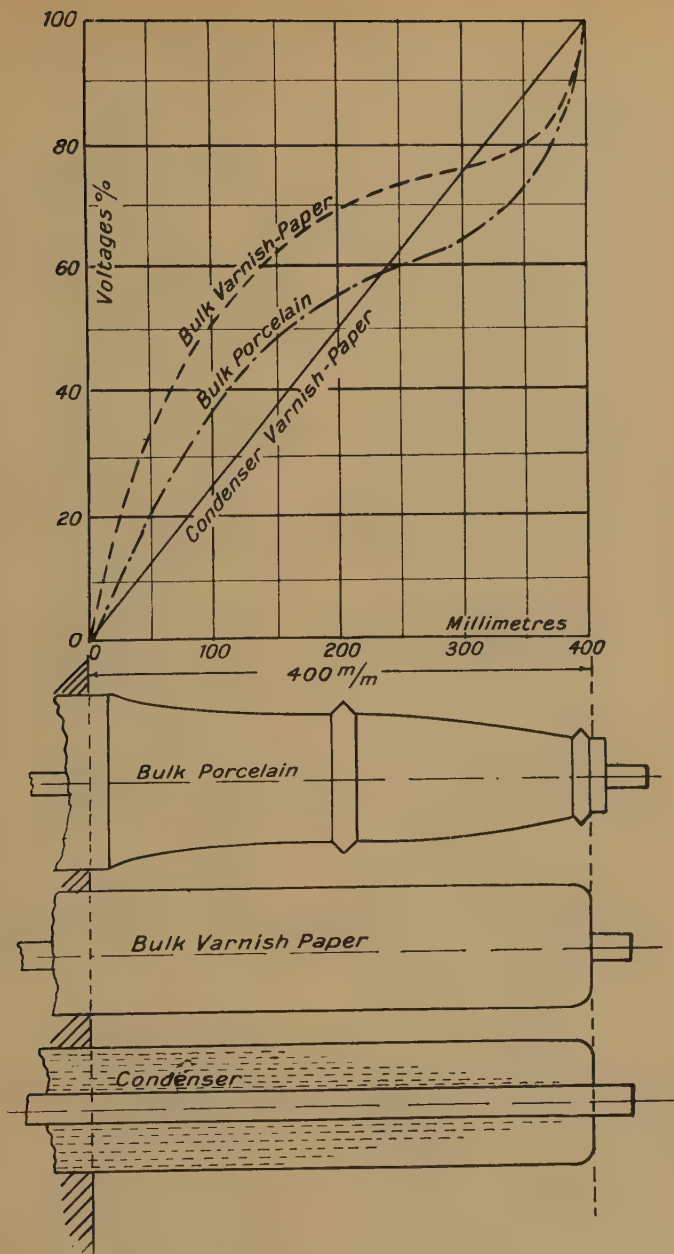


FIG. 20.—Potential Gradient on a H.T. Terminal.

transformers, lifting and operating links in H.T. switchgear and in the manufacture of radio apparatus. In the form of tubes and cylinders, this class of insulation is very largely used for transformer insulation, particularly as insulation between the high and the low voltage windings on core type transformers. Another very special application is in the form of lead in terminal bushings for H.T. transformers and switchgear. Fig. 19 shows a selection of varnish paper products made by the Micanite and Insulator Co., of London.

Condenser Type Bushings.

The so-called condenser type bushing is essentially a varnish paper product. A cross-section of a bushing of this kind made by the Metropolitan-Vickers Electrical Co., Ltd., is shown in Fig. 18, from which its general construction will be seen. It is virtually a thick-walled varnish paper tube into which a number of concentric layers of metal foil or other form of metal is introduced at carefully calculated intervals. The area of these layers of metal and their spacing is calculated so as to distribute the potential gradient evenly throughout the thickness of the material. Fig. 20 shows the potential gradient on a H.T. terminal which has been wound from varnish-treated paper with and without any condenser layers being included. The latter is usually referred to as a bulk type varnish paper bushing. The figure also shows the distribution with a bulk type porcelain bushing of similar capacity. In manufacture, these bushings are very similar to the cylindrical type condensers used for lightning protection, and the same precautions for drying the materials employed and eliminating moisture must be observed if consistent results are to be obtained. Fig. 21 shows condenser type bushings made by the Micanite and Insulator Co., of London. These actual bushings are designed to withstand a flash voltage of 250,000 volts without flashing over, and although nominally for operation on an 88,000 volt circuit, they will withstand a voltage of 115,000 volts continuously, even with one end in hot insulating oil at 90° C. The figures are quoted as being characteristic of what tests bushings of this kind should withstand.



(Outdoor type.)



(Indoor type.)

FIG. 21.—Condenser Terminals
Made by the Micanite and Insulator Co., Ltd., London.

The theoretical design of bushings of this kind has been dealt with (amongst other authorities) by A. B. Reynder, "Condenser Type of Insulation," *Transactions of the American I.E.E.*, Vol. 28, 1909, pages 209-220; R. Nagel, in *Elektrische Balmen und Betrieb*, 1906; Fortesque and Farnsworth "Application of a Theorem of Electrostatics to the Solution of Insulation Problems," *Transactions Amer. I.E.E.*, Vol. 32 (Part I), 1913; and finally by W. A. Coates, in the *Metropolitan-Vickers Gazette*, Sept., 1921, p. 200.

Synthetic Varnish Fabric Products.

A large number of proprietary materials are available, made from cotton fabric pressed up into boards with synthetic varnishes as bonds. These materials have been included in Table XIV. Their principal use is in connection with the manufacture of such articles as gears, aeroplane propellers, fan blades, etc., but they are also applied to a limited extent as insulators, although they have neither the mechanical strength nor the electrical strength of well-made synthetic varnish paper products.

Synthetic Varnish Asbestos Fabric (Bakelite-Asbestos) Products.

(Under E.R.A. classification these are Grade C.)

For high temperature work such as insulating packing blocks etc., in machines built to work at the higher temperatures now permitted under B.E.S.A. Specifications for Class B insulation, a number of materials have appeared on the market made with asbestos fabric pressed up with a synthetic varnish bond. The general characteristics of these products are shown in Table XIV, but it should be noted they have very poor electrical strength values, and, like all synthetic varnish products so far produced, are subject to tracking. They can, therefore, not be regarded as good insulators.

Standard Specifications.

The E.R.A. has recently published (see *I.E.E. Journal*, Vol. 62, No. 326, p. 160) "Directions for the Study of Varnish Paper and Varnish Fabric Boards and Tubes." In the absence

of a B.E.S.A. Specification, this document (in accordance with which the values given in Table XIV have been obtained) may be regarded as a standard test specification for these materials. The A.S.T.M. has not yet published a specification definitely dealing with these materials. The American Bureau of Standards has, however, published some information on this subject in their *Technological Publication No. 216*, 21st July, 1922.

List of Products and Trade Names of Materials Recognized as Varnish Paper (and Varnish Fabric) Products.

ASBESTITE. A synthetic varnish asbestos paper product made by the Swiss Insulating Works, Bretonbac (Soleure).

BAKELAGUE. A trade name applied by Attwater & Sons, of Preston, to a number of synthetic resin products, including synthetic varnish paper boards and tubes.

BAKELITE. The name of the original commercially applied synthetic resin introduced by Dr. Baekeland. The term is frequently used to describe varnish paper products, etc., made with a synthetic resin binder; but this use of the term is strongly to be deprecated, as it leads to confusion with "Bakelite" as applied to mouldings and other products.

BAKELITE-DILECTO. A synthetic varnish paper product made by the Continental Fibre Co. of America, in seven grades—

Grade X.	Grade G.
Grade X. Extra hard.	Grade A made with asbestos.
Grade XX.	Grade S made with paper
Grade XXX.	and hard rubber.

BICARTON. A product made with synthetic varnish and pressboard used by Brown Boveri & Co.

BITUBA. A synthetic varnishpaper product employed by Brown Boveri & Co.

CANEVASITE. A synthetic varnish canvas product made by the Swiss Insulating Works, Bretonbac (Soleure).

CARTA and SPEZIALKARTA. These are varnish-paper products produced by Continental Isola-Werken A.-G., of Duren bei Birkesdorf.

CARTOGENE. A synthetic varnish paper product made by Presspahn and Electrical Insulating Material Manufacturing Co. (formerly H. Weidmann), Rapperswil, Switzerland.

CONDENSITE-CELERON. Products made by the Diamond State Fibre Co., of U.S.A., with synthetic varnish (Condensite) as a binder, but with the following base materials—

Grade 10 and 15.	Vulcanized fibre.
Grade 20 and 25.	Duckcloth.
Grades 30 and 35.	Asbestos.

CONTINENTAL-BAKELITE. A synthetic varnish fabric product made by the Continental Fibre Co. of America, in two grades—

Grade CB made with 20 mil thickness duckcloth.

Grade CBL made with 5 mil thickness cambric.

DELLITE. A synthetic varnish paper product produced by the Swiss Insulating Works, Bretonbac (Soleure). Dellite is also produced with thin presspahn instead of paper. It is also produced by the Usines Dielectriques de Delle in France.

ELO. A synthetic resin product made by Birkby, of Liversedge, Yorkshire, but not supplied as a varnish paper product. (See Chapter VI and appendices to Chapter XIV.)

ETRONITE. A synthetic resin paper product produced in Norway, and sold by J. B. Hamilton, of 73 Cheapside, London, E.C.2.

FORMICA. A range of products made with synthetic varnish (Redmanol) as a binder. Produced by Formica Insulation Co., of Cincinnati, Ohio, in four grades—

Grade M made with paper and Redmanol-phenol varnish.

„ M₂ made with paper and Redmanol-cresol varnish.

„ P made with paper and Redmanol-cresol varnish.

„ R made with canvas.

GEAX. A synthetic varnish paper product made by Allgemeine Elektrizitäts Gesellschaft.

HAEFELYTE. A shellac varnish paper product made by A. G. Emil Haefely, of Basle.

JEWELITH. See Chapter VI.

KOPAN. See Chapter VI.

MICAFIL B. A synthetic varnish paper product made by Micafil S.A. Zurich-Altstettin, Switzerland.

MICAFIL S. A shellac varnish paper product made by Micafil S.A. of Zurich. *Note.*—Must not be confused with “Micafil G.,” a varnish paper product containing mica, and therefore probably more correctly described as a micafolium product. (See Chapter XVI.)

MICARTA. The term “Micarta” covers a range of varnish paper and varnish fabric products produced by the Westinghouse Electric and Manufacturing Co., employing both natural and synthetic resin varnishes as bonds. The term has been used by Emil Haefely and other makers to describe similar products. “Micarta,” as a general rule does not contain any mica. The fabrics employed include duckcloths, cambric and asbestos cloth. Various classes of papers are also utilized to produce the different grades of micarta.

MIOCARTA. A synthetic varnish paper product made by the Ioco Rubber and Waterproofing Co., Anniesland, Glasgow.

PAXOLIN. A synthetic varnish paper product made by the Micanite and Insulator Co., Ltd., Walthamstow, London, in several grades.

PERTINAX. A synthetic varnish paper product made in numerous grades by Mierowski A.-G. Porz-am-Rhein, Germany.

PIRTOID. A synthetic varnish paper product made by H. Clarke & Co., of Salford, Lancs.

PRESSZELL. A synthetic varnish paper product made by Allgemeine Elektrizitäts Gesellschaft. (See “E.T.Z.,” No. 9, 28th February, 1924, p. xxv.)

REDMANOL. (See Formica.)

REPELIT. A synthetic varnish paper product made by the Siemens Schuckertwerke, of Berlin.

SOUTHALITE. A synthetic varnish paper product made by the Siluminite Insulator Co., Ltd., Southall, Middlesex.

SPEZIALKARTA. (See Carta.)

SUPER-BA. A synthetic resin made by Monte & Martini, of Milan, and used for building up "Super-ba" varnish paper products.

TURBAX. A synthetic varnish canvas material produced by Jaraslaws Erste Glimmerwaren-fabrik.

TURBONIT. A synthetic varnish paper product made by Jaraslaws Erste Glimmerwaren-fabrik, Berlin.

WAHNERIT. A synthetic varnish paper product made by Electro-isolier-industrie M.B.H. Wahn, Rheinland.

CHAPTER X

TIMBERS

THE woods of commerce are the lignified secondary tissues of a number of coniferous and dicotyledonous plants. This secondary tissue is distinguishable into an older internal portion known as the heart wood (duramen) and a younger outer portion known as the sap wood (alburnum). In the living tree these secondary tissues only form a portion of the whole, and correspond in many respects to the bones of the human body in that they act as a support to the vital organisms of the plant, including the complex system of cambium ducts which pass up the tree just under the bark. In all trees the growth of the wood cells is more rapid in spring time than in the autumn, and hence the concentric layers of wood cells found in any one year show smaller cells in the tissue as the summer proceeds. The result is that the cross-section of nearly any tree shows so-called annular rings, from which it is possible to estimate the age of the tree. Some plants contain very much more uneven tissues in these annular rings than others. In coniferous trees this difference is accentuated, due to the fact that the spring wood is formed of particularly thin-walled tracheidal cells, whereas the autumn wood consists of cells of much thicker walls. In certain dicotyledonous trees, as, for instance, beech, lime, maple, and walnut, there is almost an inappreciable difference between the spring and autumn growths. Oak, elm, and ash, on the other hand, are distinguished by very pronounced enlargement of the spring wood cells.

In the timber trade a distinction is made between "Hard Woods" and "Soft Woods." The soft woods are generally defined as the woods from "narrow leaved" trees, and therefore include all coniferous trees, even extending to the yew tree. The hard woods are those of "broad leaved" trees, which are as a rule more slow growing, and therefore produce denser timber. In this case, too, there are outstanding

TABLE XV
PROPERTIES OF TIMBERS USED FOR INSULATING PURPOSES

Name.	Botanical Name.	Colour, etc.	Spec. Grav.		U. T. S. in lb./□"		Compress. Str. lb./□"	
			Min.	Max.	Min.	Max.	Min.	Max.
<i>Soft Woods—</i>								
Pine (Red, Yellow Deal)	<i>Pinus sylvestris</i>	Light reddish yellow	.34	.41	2,900	14,000	4,800	7,500
Spruce (White Deal)	<i>Picea excelsa</i>	White	.46	.55	3,000	11,800	3,000	6,800
Larch . . .	<i>Larix europea</i>	White	.53	.55	4,000	11,000	3,200	5,500
Pitchpine Pine . . .	<i>Pinus palustris</i>	Red and yellow	.64	.93	4,800	12,000	4,700	6,800
Red Canadian Pine . . .	<i>Pinus strobus</i>	Reddish white						
American White Pine . . .	<i>Pinus strobus</i>	Reddish white						
Oregon Pine. . .	<i>Pseudotsuga Douglasii</i>	Reddish white						
<i>Hard Woods—</i>								
Ash . . .	<i>Fraxinus excelsior</i>	White to brownish white	.70	.80	12,000	17,000	8,600	9,300
Beech . . .	<i>Fagus sylvatica</i>	Yellowish brown	.70	.75	11,000	22,000	7,700	9,300
Boxwood . . .	<i>Buxus sempervirens</i>	Yellowish white		1.28		20,000		10,300
Ebony. . .	<i>Diospyros ebenum</i>	Black		1.18		19,000		
Elm . . .	<i>Ulmus campestris</i>	Dark brown	.55	.75	4,480	9,200	5,600	9,200
Green Heart. . .	<i>Nectandra rodioei</i>	Dark green brown	.93	1.15	8,000	9,200	12,000	15,200
Hickory . . .	<i>Hicoria alba</i>	Brownish white				11,000		9,500
Hornbeam . . .	<i>Carpinus betulus</i>	Yellowish white		.75	15,000	20,000	4,600	8,500
Jarrah. . .	<i>Eucalyptus marginata</i>	Red		.56	13,400	15,500	6,250	9,500
Kouri Pine . . .	<i>Agathis australis</i>	Straw colour		1.33		9,600		10,000
Lignum Vitae . . .	<i>Guaicum officinale</i>	Greenish brown		.75	10,600	15,400	6,000	
Maple . . .	<i>Acer saxxharum</i>	Cream colour	.67	.75	6,000	19,000	6,400	10,000
British Oak . . .	<i>Quercus robur</i>	Light brown	.78	.93				
Baltic Oak . . .	<i>Quercus pedunculata</i> and } <i>quercus sessili flora</i>	Light brown	.80	.96	6,500	14,000	6,000	7,000
Austrian Oak . . .		Light Brown						
American Oak . . .	<i>Quercus alba</i>	Light Brown	.80	.96	6,720	12,000	6,000	6,900
Salmon Gum . . .	<i>Eucalyptus salmonophloia</i>	Brown			16,900	19,200	8,100	10,700
Teak . . .	<i>Tectona grandis</i>	Creamy yellow	.66	.98	4,000	15,000	8,500	12,000
Tuart . . .	<i>Eucalyptus gamphocephala</i>	Greyish brown			13,300	16,500	6,970	16,500
Walnut . . .	<i>Juglans regia</i>	Red brown	.45	.50	7,600	8,120	6,000	7,200
Yew . . .	<i>Taxus baccata</i>	Dark red	.79	.80	8,000			
Mahogany . . .	Name covers many species	Dark red	.56	.67	3,400	18,000	6,000	8,000
Satinwood . . .	Name covers many species	Chrome yellow		.96				

exceptions of soft timbers being classed as "hard woods" because they are cut from broad-leaved trees.

SOFT WOODS are not in general used as actual insulators, except in temporary work, but in view of their importance in many applications closely akin to insulation work, some details of their properties have been included in Table XV.

HARD WOODS used as insulators include—

Lignum vitae, which is machined into bushings and small parts for carrying contacts in instrument and switchgear work. The insulation of train control jumper contacts is frequently made from this material. Its cost prohibits its use for larger work.

Maple is extensively used, after treatment with linseed oil, as finger boards in controllers, contact carriers for reverse drums in controllers, spacing blocks and strips in alternators and transformers, wedges, frames for reactance coils, etc. This timber has the advantage of being moderately cheap and yet hard and close grained. It readily absorbs oil and does not warp seriously.

Teak is used for much the same purposes as maple, but, in addition, is used for railway shoe beams, for which purpose it is well suited.

Jarrah, in view of its non-inflammability, is probably an ideal timber for railway shoe beams and for insulation on traction work, for which purpose it is already in use. Another important property of jarrah is that it is immune from dry rot and that it resists the attacks of white ants to a great extent.

Oak is used for many of the same purposes as maple and teak, but unfortunately it is extremely variable in quality, since several species of *Quercus* are cut and imported under the same name.

Hickory, *Ash*, and *Hornbeam* are all used for operating handles, lifting rods, etc., for switchgear. *Hornbeam* is also used for slot wedges, being specified for that purpose by the British Admiralty.

Elm, *Satinwood*, *Mahogany*, and *Walnut* are all used in electrical work, the latter two particularly where finish is of

importance, as in manufacture of radio receiving sets, telegraph apparatus, laboratory equipment, etc. For these purposes, however, they do not serve as insulators.

OTHER TIMBERS. Recent timber exhibits shown in London indicate that there are many foreign woods available, the technical properties of which have never been fully realized in Europe. There is every indication that certain of these timbers may find an application in electrical work, particularly for slot wedges and other places where toughness, strength, and minimum shrinkage are of importance. For instance, samples of yate (*Eucalyptus cornuta*) have shown a U.T.S. of 39,200 lb. per sq. in., and this timber is shown by Western Australian Government tests to have an average U.T.S. of 24,200 lb. per sq. in.

PLYWOOD. Plywood has been adopted of recent years as an insulation material for barriers in oil switches, linings for oil tanks, and similar work. This product consists of thin veneer sheets cut from well-seasoned timber glued and pressed together with the grain in adjacent laminae at right angles. The pressure employed is approximately 5 to 8 lb. per sq. in. The thickness of the laminae is generally less than $\frac{1}{16}$ in. The adhesive used is usually a waterproof glue of the casein or the blood-albumen kind.

Seasoning of Timber.

The object of seasoning timber is to effect the elimination of the sap which is left in the cells of the wood after the tree has been felled and sawn to rough timber. In the process of seasoning, timber loses weight and shrinks. Oak, for instance, loses from 14 to 30 per cent by weight, depending on the season of the year it is cut, and shrinks 3 per cent in dimensions during the seasoning process.

Natural seasoning is universally agreed to give the best results and consists in merely leaving the timber to dry naturally in stacks, in which air has free access to circulate round each individual piece. Protection from ground-damp and rain, etc., is provided, because irregularities in moisture conditions tend to produce splitting. The period of exposure may vary from three months to as many years, depending on

the kind of tree and its size. The largest oak timber, for instance, should have at least 26 months seasoning period, whereas small oak timber will season in 6 to 8 months. Water seasoning is frequently resorted to in order to save time, since it has been found that, by simple osmosis, water will very quickly displace sap in any timber. Two or three weeks' immersion suffices to free the wood of its sap, when it may be quickly dried (in kilns) ready for sawing. Water-seasoned timber is brittle and mechanically weak in comparison with air-seasoned timber. Steam seasoning is a modification of water seasoning and has the same disadvantages.

Drying of Timber.

All timbers, the previous history of which is not known, should be dried before being used for insulation purposes. Care must be taken that the drying temperature is not excessive at the commencement, and for most timbers initial temperatures in excess of 60°C . will probably produce trouble unless the wood is exceptionally well seasoned. Later the temperature may safely be raised up to that used in baking insulating materials in general, i.e. 100 to 110°C .

When impregnating with linseed oil, it has frequently been found that the impregnation is more easily effected with wood which is not too well dried.

Impregnation and Oil Boiling.

For insulating work, woods are very frequently not vacuum impregnated, but merely submitted to boiling in linseed oil for a period of 12 to 18 hours or more. Vacuum impregnation with oils, resins, synthetic resins, and compounds, has also been resorted to. Such methods are adopted to render the material less hygroscopic and improve its insulation characteristics.

Preserving and Fireproofing.

For conduit work, troughing, etc., timber is frequently subjected to impregnation with various preservative compounds to protect it from rotting, fermenting, or attack from insects. Creosote, bichloride of mercury, zinc chloride, copper

sulphate, anthracene, cresol and milk of lime, nathalene, and a large number of similar and proprietary compounds are used for this purpose. Impregnating methods are also used to render timbers fireproof by treating with fireproofing liquids, such as oxylene (a mixture of 12 parts of ammonium phosphate, 1 part boracic and 87 parts water), silicate of potash, alum and borax (in equal parts), zinc chloride, and similar compounds.

Standard Specifications.

There are no existing B.E.S.A. specifications for timber for electrical purposes (unless B.E.S.A. Specification No. 139/121, red fir wood poles for telegraph and telephone lines may be considered as such). The A.S.T.M. and V.D.E. have also no issued specifications directly dealing with timbers for electrical insulation work.

CHAPTER XI

BITUMENS AND FILLING COMPOUNDS

BITUMINOUS compounds adapt themselves well for many electrical insulating purposes on account of their high electric strength and resistance to moisture, acids, and alkalis. Unfortunately, even amongst users, there appears to be considerable confusion amongst such terms as "bitumen," "asphalt," "asphalite," "pitch," "tar," etc., so that the exceedingly detailed classification given by Abraham in *Asphalts and Allied Substances* (D. van Nostrand & Co., New York, U.S.A.) is interesting, as it provides a definition of the terms used to describe the 56 different classes of bituminous products, the majority of which find some commercial application in the electrical industry. Table XVI is based on Abraham's classification.

The technical requirements in bitumen compounds for electrical work naturally vary for the various uses to which the materials are to be put, and although no general rules can be set down, the following briefly summarizes modern practice.

Vacuum Impregnating Compounds.

For the vacuum impregnation of armature coils, field coils, etc., residual asphalts are usually employed (although refined native asphalts are also used). Residual oil and wax tailings are generally employed as fluxes in order to retain the compound at its normal consistency, since the frequent heating and cooling tends to raise its softening point. The general properties of bitumens are shown in Table XVII.

Details of the plant employed for this work are outside the scope of this book, but the equipment consists substantially of two steam-heated air-tight steel (or iron) tanks, one for containing the compound in a fluid form and the other for containing the work to be impregnated. The coils are put into the second tank; after drying in vacuum for several hours, the vacuum is broken with the hot fluid compound, and the

TABLE XVI
CLASSIFICATION OF BITUMENS

Classification and Name of Product.	Remarks.	Class of Insulation Material in which used. —
BITUMENS—		
<i>A. Petroleum :</i>		
Non-Asphaltic . . .	Contain appreciable amount of crystallizable paraffin and no asphalt	Transformer oils (American)
Mixed Base . . .	Contain crystallizable paraffin and also asphalt	Transformer oils
Asphaltic . . .	Contain an appreciable quantity of asphalt and no crystallizable paraffin	Transformer oils (Russian)
<i>B. Native Mineral Waxes</i>		
Ozokerite . . .	A paraffinaceous mineral called ceresine when refined	Cable insulation and filling
Montan Wax . . .	A wax extracted from lignite or pyropissite by means of solvents	Cable insulation and filling
<i>C. Native Asphalts :</i>		
	Pure or fairly pure—i.e. less than 10% on dry weight Associated with mineral matter—i.e. sand, sandstone, limestone, clay, and shale	Moulded compositions
<i>D. Asphaltites :</i>		
Gilsonite . . .	Extremely pure. Fusing point higher than for asphalts—derived from petroleum	Varnish manufacture and insulating cements Also in moulded compositions
Glamce Pitch . . .	Ditto, but may be only moderately pure	Insulating cements
Grahamite . . .	Ditto, but may be quite impure	
PYROBITUMENS—		
<i>A. Asphaltic Pyrobitumens :</i>		
Elaterite . . .	Generally pure, infusible and insoluble derived from petroleum. Rubbery and partly saponifiable	Moulded compositions
Wurtzilite . . .	Generally pure, infusible and insoluble—derived from petroleum. Depolymerizes on heating becoming fusible and soluble	
Albertite . . .	Generally pure, infusible and insoluble. Derived from petroleum. Depolymerizes partially on heating	
Impsonite . . .	Generally pure, infusible and insoluble Derived from petroleum. Does not depolymerize on heating	
Asphaltic pyrobituminous Shales	Mineral matters predominate Infusible and insoluble	

TABLE XVI—(contd.)

Classification and Name of Product.	Remarks.	Class of Insulation Material in which used.	
B. Non-Asphaltic Pyrobitumens :			
Peat Lignite Bituminous Coal Anthracite Coal	Pure or fairly pure, infusible and insoluble. Contains more or less oxygenated bodies. Derived from vegetable growths. Gradual transition from peat to coal		
Lignitic and Coal Shales			
Mineral matters predominate Otherwise same as foregoing			
PYROGENOUS DISTILLATES—			
A. Pyrogenous Waxes :			
Petroleum Paraffin	Solid paraffin obtained from non-asphaltic petroleum	Sealing and moisture proofing special E.H.T. insulation on induction coils, etc.	
Peat Paraffin	Solid paraffin from peat tar		
Lignite Paraffin	Solid paraffin from lignite tar		
Shale Paraffin	Solid paraffin from shale tar		
B. Tars :			
Oil Gas Tar	Produced by cracking petroleum vapours in manufacturing oil gas		
Water Gas Tar	Produced by cracking petroleum vapours in manufacturing carburetted water gas		
Pine Tar	Produced by destructive distillation of the wood and roots of coniferae		
Hardwood Tar	Produced by the destructive distillation of hardwoods		
Peat Tar	Produced by the destructive distillation of peat		
Lignite Tar	Produced by the destructive distillation of lignite		
Shale Tar	Produced by the destructive distillation of pyrobituminous shales		
Gasworks Coal Tar	Produced from gas-house retorts in manufacturing gas from bituminous coal		
Coke-oven Coal Tar	Produced from bye-product in manufacturing coke from bituminous coal		
Blast Furnace Coal Tar	Produced from blast furnaces when smelting with bituminous coals		
Producer Gas Coal Tar	Produced from gas producers in manufacturing producer gas from coal		
Bone Tar	Produced by the destructive distillation of bones		

TABLE XVI—(contd.)

Classification and Name of Product.	Remarks.	Class of Insulation Material in which used.
PYROGENOUS RESIDUES—		
<i>A. Pyrogenous Asphalts :</i>		
Residual Oils . .	Produced by the dry distillation of non-asphaltic petroleum, the dry or steam distillation of mixed base petroleum, or the steam distillation of asphaltic petroleums	Fluxes for impregnating compounds
Blown Petroleum Asphalts	Produced by blowing through heated residual oils	Rubber substitute compounds, etc.
Residual Asphalts	Produced by the steam distillation of mixed base and asphaltic petroleums	Vacuum impregnating compounds. Joint box compounds. Varnishes (hard asphalts only)
Sludge Asphalts .	Produced from acid sludge obtained in the purification of petroleum distillates with sulphuric acids	
Wurtzilite Asphalt	Produced by depolymerizing wurtzilite in closed retorts	Rubber substitute Moulded compositions
<i>B. Pitches :</i>		
Oil Gas Pitch	Residues obtained by the partial evaporation or distillation of the respective tars	
Water Gas Pitch		
Wood Tar Pitch		
Peat Tar Pitch		
Lignite Tar Pitch		
Shale Tar Pitch		
Gasworks Coal Tar Pitch		
Coke-oven Coal Tar Pitch		
Blast Furnace Coal Tar Pitch		
Producer Gas Coal Tar Pitch		
Bone Tar Pitch		
Rosin Pitch	Residue from partial distillation of resinous sap of coniferae	Varnishes (hard pitch only) Rubber substitute Varnishes (hard pitch only)
Fatty Acid Pitch	Residue obtained from steam distillation of fatty acids	

TABLE
(Reproduced from Paper by Maxwell and Monkhouse.)

GENERAL CHARACTERISTICS OF

Genus.	Species.	Member.	Colour in Mass.
BITUMENS	Petroleums	Non-asphaltic	White to yellow to brown
	Native mineral waxes	Mixed-base	
		Asphaltic	
		Ozokerite	
		Montan wax	
	Native asphalts	Pure or fairly pure	Black
	Asphalites	Associated with mineral matter	
		Gilsonite	Black
		Glance-pitch	Black
		Grahamite	Black
PYROBITUMENS	Asphaltic pyrobitumens	Elaterite	Black
		Wurtzilite	Black
		Albertite	Black
		Impsonite	Black
		Asphaltic pyrobituminous shales	Brown to nearly black
	Non-asphaltic pyrobitumens	Peat	
		Lignite	
		Bituminous coal	
		Anthracite coal	
		Lignitic and coal shales	
PYROGENOUS DISTILLATES	Pyrogenous waxes	Wax tailings	Yellow
		Petroleum paraffin	Pure white to yellowish
		Peat paraffin	
		Lignite paraffin	
	Tars	Shale paraffin	Black
		Oil-gas tar	Black
		Water-gas tar	Brownish
		Pine tar	Black
		Hardwood tar	Black
		Peat tar	Black
		Lignite tar	Yellowish brown to black
		Shale tar	Brownish black
		Gasworks coal tar	Black
		Coke-oven coal tar	Black
		Blast-furnace coal tar	Black
		Producer-gas coal tar	Black
		Bone tar	
PYROGENOUS RESIDUES	Pyrogenous asphalts	Residual oils	Black
		Blown petroleum asphalts	Black
		Residual asphalts	Black
		Sludge asphalts	Black
	Pitches	Wurtzilite asphalts	Black
		Oil-gas-tar pitch	Black
		Water-gas-tar pitch	Black
		Wood-tar pitch	Black to brownish black
		Peat-tar pitch	Black
		Lignite-tar pitch	Black
		Shale-tar pitch	
		Gasworks coal-tar pitch	Black
		Coke-oven coal-tar pitch	Black
		Blast-furnace coal-tar pitch	Black
		Producer gas coal-tar pitch	Black
		Bone-tar pitch	
		Rosin pitch	Black
		Fatty-acid pitch	Dark brown to black

Read before I.E.E. on 23rd April, 1925)

SOME BITUMINOUS MATERIALS

Fracture.	Lustre.	Specific Gravity at 25° C.	Dropping Point.		Electric Strength, V/mil.
			Kramer-Sarnow	Ring and Ball.	
			° C.	° C.	
Conchoidal	Dull to waxy	0.85-1.0	60-93		100-140
Conchoidal		0.90-1.0	77-93		
			88-93		
Conchoidal	Bright	1.006-1.01	81-11		100-400
Conchoidal	Dull	1.40-1.42	86-67		
Conchoidal	Bright	1.05-1.1	121-177	132-190	100
Conchoidal to rough	Bright	1.10-1.15			
Conchoidal to rough	Very bright to dull	1.15-1.2	177-315	187-329	
Conchoidal	Bright	0.9-1.05			
Conchoidal to rough	Bright	1.05-1.07	Decomposes		
Rough	Bright	1.07-1.10	Decomposes		
Sub-conchoidal	Semi-dull	1.10-1.25	Infusible		
	Dull	0.9-1.32	Infusible		
Conchoidal to rough	Waxy	1.0-1.1	15.5-37		
	Dull to waxy	0.85-0.95	37-65	40-71	
		0.95-1.1	-17 to -6		
		1.05-1.15	-17 to -12		
		1.05-1.1	10		
		1.1-1.2	-6		
		0.9-1.05	4.4-15.5		
		0.85-1.05	15-32		
		0.85-0.95	15-32		
		1.1-1.3	-3.9		
		1.1-1.3	-3.9		
		1.1-1.3	-3.9		
		1.1-1.3	-3.9		
Soft, hard, conchoidal	Bright to dull	0.85-1.05	-17.8 to 26	-12 to 35	120-350
Hard, conchoidal	Variable	0.9-1.07	26-148	37-162	
Conchoidal	Bright	1.0-1.17	26-107	37-121	
Conchoidal	Bright	1.05-1.2	26-107	37-121	
Conchoidal	Bright	1.04-1.07	65-148	76-152	
Conchoidal	Bright	1.15-1.3	26-135	37-148	100-300
Conchoidal	Bright	1.1-1.2	26-135	37-148	
Conchoidal	Bright to dull	1.1-1.3	37-93	37-148	
Conchoidal	Very bright when fresh	1.05-1.2	32-121		
Conchoidal	Variable	1.15-1.4	26-148		
Conchoidal	Variable	1.2-1.35	26-148		
Conchoidal	Variable	1.2-1.3	26-148		
Conchoidal	Variable	1.2-1.35	26-148		
Conchoidal	Dull	1.08-1.15	48-93		
None to conchoidal	Bright	0.9-1.1	1.7-107	10-118	

pressure in the tank raised to approximately 100 lb. per sq. in. This condition is maintained for an hour or two ; the compound is then returned to the compound tank, and the impregnated coils can be removed for drying and finishing.

Joint Box Compounds.

Joint box compounds are used for filling cable joint boxes, trifurcating boxes, etc., and usually consist of good grade pyrogenous asphalts with a relatively low softening point. High softening point and brittle materials tend to develop hair cracks and are not, therefore, used. An enormous number of trade and proprietary compounds are on the market for this work, some of which are included in the Appendix to this chapter. With the majority of these products the secret of making a success of the insulation is in the process of pouring rather than in the material. Precautions are necessary to heat the boxes, and other parts with which the hot compound is to come in contact, before the pouring is commenced. Pouring should also be done with a special container built as an extension to the box, being filled so that there is a " head " of liquid compound above the box itself during pouring and cooling. If a second opening in the box can be provided so that the compound may be allowed to " run through " a little, this is an advantage.

The A.S.T.M. has recently issued " Tentative Specification for Testing Cable Splicing and Pot Head Compounds. No. D 176-23 T."

Battery Box Compounds.

Coal tar pitch is frequently mixed with silica sand in equal proportions by weight in order to make a cement suitable for sealing batteries, dry cells, terminals, etc. A cement of this kind should withstand temperatures up to 75° C. without softening.

Bitumen Treated Insulating Tape.

Bitumen treated insulating tape has already been referred to (Chap. IV). Pure natural asphalts, residual asphalts, blown petroleum asphalts, wurtzilite asphalt, and fatty acid pitch are all used, either singly or in various compositions for treating

tape. These materials are frequently fluxed with soft asphalts, residual oil, animal oil, vegetable oils, or wool grease to give flexibility.

Abraham, in *Asphalts and Allied Substances*, page 439, quotes figures indicating what properties should be expected in tape-treating compounds, but since the figures all relate to empirical methods of test not standardized in Great Britain, no object will be attained in quoting them. In general the compound should possess what is called "a low susceptibility factor"—that is, should not be highly susceptible to temperature changes, and should show as high as possible a durability value on being elongated in one of the standard forms of ductility testing machines. The fusing point or melting point by the ball and ring method (see Appendix I) should be from 40 to 50° C., and the volatile matter expelled after heating for four hours at 260° C. should not exceed 5 per cent. (A.S.T.M. Test D 6-20.)

The penetration test (see Appendix I) should show a value less than 7.

Bitumen Coated Papers.

For certain telephone cable work and other purposes, bitumen coated papers are employed. These are produced by impregnating with bitumen compounds of the nature of those dealt with above under the heading of Impregnating Compounds. Fig. 22 shows results obtained on papers of this kind.

Bitumen for Cable Insulation.

Vulcanized bitumen cable insulation has already been referred to in Chapter V.

For this purpose, refined asphalts are employed which are vulcanized with sulphur.

This material has an appearance similar to that of vulcanized rubber. It is, however, less resilient than rubber and possesses the property of being quite unaffected by prolonged exposure to hot transformer oil. It also resists acid, but is susceptible to strong alkalis. Its tensile strength is much inferior to that of vulcanized rubber.

Trough Filling Compounds (for Solid System Cables).

Cables laid on the so-called solid system are laid in stoneware, iron, or wooden troughs, and then "filled in" with a bitumen compound. The material most generally used for this purpose is natural asphalt in the form of Trinidad bitumen heated to

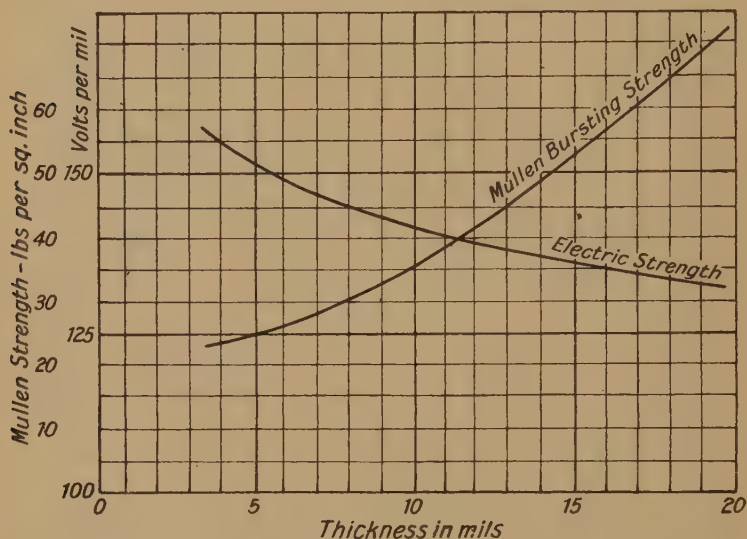


FIG. 22.—Bursting and Electric Strength of Bitumen Coated Insulating Papers.

approximately 150° C. before pouring. Residual asphalts are also employed for this work. Where pitches are employed they are softened by the addition of approximately 5 per cent creosote oil, since otherwise they would be too brittle. Another mixture employed consists of pitch mixed with approximately 40 per cent of stone dust.

Natural Mineral Waxes.

Mineral waxes have been included in Table XVI as bitumens. Certain of these waxes occur in nature as oxidation products of petroleum, whilst others occur in lignite and peat deposits. They are utilized in the electrical industry in connection with cable insulation.

OZOKERITE, or "Earthwax," is found in Galicia, Caucasus, and North America. It is produced by the natural oxidation of petroleum, and is frequently found mixed with petroleum. The crude wax as taken from the ground is melted in large kettles to allow adherent mineral matter to separate by gravity. The pure wax can be skimmed from the surface, boiled to evaporate water, and cast into blocks.

The chief source of ozokerite is the district of Borislav, in Galicia. The crude wax is found in a number of qualities, varying in colour from pale yellow to black.

CEREZINE WAX. Cerezine wax is produced by refining ozokerite by a process involving heating to 140 to 150° C., together with 20 to 25 per cent by weight of fuming sulphuric acid and animal charcoal. The result is a bleached and almost pure white wax which has a melting point slightly higher than that of ozokerite. Otherwise cerezine and ozokerite have practically the same properties, which include: specific gravity, .91 to .92 at 15.5° C.; fracture, conchoidal; melting point, 60 to 70° C.

SCHEERITE AND KABAITE. Scheerite and Kabaite are similar waxes which, although experimented with, have no appreciable commercial value as insulating waxes. *Hatchettite* is a variety of ozokerite occurring in Wales and Scotland.

MONTAN WAX. Montan wax is a product somewhat variable in its characteristics which is produced from lignite and other non-asphaltic pyrobitumens by extraction with volatile solvents. It melts at approximately 80 to 86° C., has a specific gravity of .90 to .98. In its crude form it is dark brown, but can be produced by distillation *in vacuo* so that it is almost white. When distilled with superheated steam it yields a white wax, to which the name "Montanic Acid" is given, and a residual pitch which has been used for electrical insulation work.

PYROGENOUS PARAFFIN WAXES. Paraffin waxes are produced by distillation processes from paraffinaceous petroleum, peat tar, lignite tar, and shale tar. The wax has a specific gravity of 0.85 to 0.92 at 15° C. according to its source. Good quality wax melts at from 55 to 60° C., but inferior qualities have melting points as low as 30° C. Paraffin wax is used as

an insulator in the manufacture of electrical condensers, induction coils, small batteries, etc. It is also added to varnishes for cloth varnishing to produce "finish" and prevent adhesion between turns in the roll.

Standard Specifications, Etc.

The B.E.S.A. has not issued any specifications for bituminous materials for insulating purposes, but the following specifications have been issued by the A.S.T.M. bearing on the subject—

D 4-11. Standard method of test for soluble bitumens.

D 5-21. Standard method of test for penetration of bituminous materials.

D 6-20. Standard method of test for loss on heating of oil and asphaltic compounds.

D 36-21. Standard method of test for softening point of bituminous materials (ball and ring method).

D 87-22. Standard method of test for melting point of paraffin wax.

D 113-22T. Tentative method of test for durability of bituminous materials.

D 147-23T. Tentative specifications for testing bituminous mastics, grouts, and like mixtures.

D 176-23T. Tentative methods of testing cable splicing and pot head compounds.

List of Products and Trade Names of Materials dealt with as Bitumens, Filling Compounds, Waxes, Etc.

CHATERTON COMPOUND. A special compound devised originally by Chaterton (see Submarine Cable Report of 1861) for filling insulating materials at joints, etc.

CONDULINE. A filling compound for cable jointing supplied by the Micanite Insulator Co., of U.S.A.

O.B. TRANSFORMER COMPOUND. A compound for the impregnation of oil-immersed transformer windings made by Pinchin Johnson & Co., Ltd.

IMPREGNITE. A name given to a number of special impregnating compounds by Pinchin Johnson & Co., Ltd.

OHMALINE. A name given to a range of vacuum impregnating compounds supplied by Griffiths Bros. & Co., Ltd., of London.

P. AND B. COMPOUND. See Chapter VI. (Varnishes.)

PETRITT. A compound made by the Dielectric Manufacturing Co., of St. Louis, Mo.

REFRAITIT. A compound made by the Dielectric Manufacturing Co., of St. Louis, Mo.

VACULITE. A compound made by the John C. Dolph Co., of Newark, N.J.

POTHEAD COMPOUNDS. A generally used term in the U.S.A. for describing what in Great Britain are called joint box or filling compounds.

PROVOL. A compound produced by W. Jones of Davyhulme, near Manchester.

CHAPTER XII

INSULATING OILS

THE oils used as insulating oils in commercial work are almost exclusively refined from crude mineral petroleum.

The origin of mineral oils is still obscure. Two eminent theories may be quoted—one organic and the other inorganic. The organic theory is the one now most generally accepted, particularly since recent discoveries in Russia have revealed the process of metamorphism in all its stages, from animal and vegetable matter to the oil-bearing sludges.

The Organic Theory.

The theory probably most nearly correct is that enunciated by Pontonie. According to his observations, the slime produced in stagnant waters is the first stage in the formation of mineral oil. This slime is produced from elementary animal and vegetable life, the remains of which putrefy and do not rot, due to the lack of oxygen in deep waters. During putrefaction the non-fatty constituents (albumens and cellulose) disappear. A grey, green purulent slime is then deposited, which is buried under subsequent deposits and forms a polymeric bitumen (bitumen and shale and boghead coal), which decomposes under the influence of pressure and heat and produces petroleum. A further stage in the metamorphism results in the oxidation and polymerization of petroleum to produce natural asphalts.

Recent researches made under the Soviet Government in Russia have shown every step in the above transformation, from the living vegetable plant *Botryococcus Browni*, a very elementary water vegetable growth of the green pond slime order—containing a considerably greater proportion of fat than is associated with higher forms of vegetable life—to oil-bearing (bituminous) shale deposits. As a matter of fact, the

recent slime from the bottom of certain lakes, including Balkash, in Turkestan, is being refined to produce the majority of the products usually distilled from crude petroleum.

It may also be pointed out that the optical activity of mineral oils is not compatible with an inorganic origin.

The Inorganic Theory.

The inorganic theory of the origin of petroleum was first put forward by Mendelejeff, and assumes that metallic carbides (formed by the action of carbon with iron and other metals), have been decomposed under water at very high pressures and temperatures, resulting in the production of hydrocarbons. A subsequent rearrangement in the molecules of these hydrocarbons has been shown by various experimenters to be capable of producing hydrocarbons homologous to those found in petroleum.

Sources of Crude Oil.

The main sources of crude oil from which transformer oils are made are: Pennsylvania (U.S.A.), California, Azerbazsan (Caucasus), and Rumania. It must not be thought that equally good transformer oils can be prepared from the different crudes—on the contrary, the crudes themselves vary greatly. The Pennsylvanian crudes, for instance, are chiefly parafinoid hydrocarbons and homologous substances with certain smaller amounts of benzol hydrocarbons (cyclic compounds), whereas the Caucasian oils are chiefly cyclic combinations such as naphthenes (C_nH_{2n} , cyclo-paraffin, etc., which are derived from cyclopentane) and aromatic hydrocarbons of composition C_nH_{2n-6} .

Transformer oils produced from such crudes differ largely with the percentage of unsaturated hydrocarbons they contain and, since it is the presence of unsaturated hydrocarbons which results in the formation of sludge when the oils are heated in the presence of air and copper, this question of composition becomes of radical importance. The transformer oils refined from Caucasian crude, with the exception of that from Grozni (North Caucasus), are singularly free from unsaturated

hydrocarbons, and these particular oils are looked upon by electrical engineers as exceptionally good transformer oils. The Pennsylvanian oils can only with difficulty be made equal to them in this respect.

The processes employed in the preparation of transformer oils and other products from crude mineral oils differ, largely depending on the nature of the oil, and on which of the various products obtainable is regarded by the refiner as of the greatest importance.

In general, however, the crude is "cracked" on the oilfields. Cracking consists of heating in a "cracking" still, and separating the distillate which comes off at different temperatures. Under the influence of heat the complex hydro-carbons constituting the mineral oil are broken down into less complex volatile and aromatic hydrocarbons, which become liberated at various temperatures according to their boiling-points.

Russian crude oil, for instance, when subjected to this process produces—

1. Up to 150° C.—Crude benzines or petroleum naphthas, specific gravity 0.75 to 0.77, which is capable of being further distilled into gasolene (specific gravity, 0.655), benzoline (specific gravity 0.705), and benzine (specific gravity 0.737).

2. 150° C. to 300° C.—Kerosenes or illuminating oils (specific gravity 0.87).

3. Above 300° C.—Residium (Russian *ostatki*) remaining in the still. This product forms the base from which lubricating oils are distilled by blowing superheated steam through the mass in the stills and collecting the distillate at various temperatures, as instanced in the following figures (applying to Russian *ostatki*)—

Name of Oil.	Distilling at ° C.	Sp. Gr.	Colour.
Solar Oils	150–170	.840–.860	Pale yellow
Insulating Oil or Light Spindle Oils.	170–200	.870–.880	Yellow
Heavy Spindle and Light Machine Oil	200–250	.895–.900	"
Engine Oil	250–300	.908–.912	Reddish brown
Cylinder Oil	300–320	.915–.920	Red
Fuel Residue.	—	.950	Black

From the above it will be seen the insulating oil fraction comes off between 170 and 200° C. This distillate is then "washed" by passing through concentrated sulphuric acid (66 per cent H_2SO_4) to remove unsaturated hydrocarbons and bases, followed by caustic alkali to remove traces of the acid; and also litharge to remove all traces of sulphur. It is then carefully dried and filtered, either by passing through blotting-paper type filter presses or in centrifugal separators.

The general properties required in insulating oil by the B.E.S.A. specification (No. 148) are shown in Table XVIII.

The standard tests specified by the B.E.S.A. in Specification No. 148 are given in full in Appendix I, and represent generally accepted British practice in oil testing.

Sludging in Transformer Oils.

Sludging in transformer oils can be the source of very serious trouble, and the development of suitable tests for determining the sludging properties of insulating oils has exercised the minds of transformer engineers for many years.

According to Mr. C. J. Rodman (*Proc. American Electrochemical Soc.*, Annual Meeting, 2nd Oct., 1921), sludge in transformer oil occurs in three forms—

1. *Asphaltic Sludge*, due to oxidation of the oil forming asphaltic deposits on the windings. Such asphaltic sludge possesses many of the properties of other asphalts and is a good insulator, but is, however, deleterious on account of its poor heat conductivity, which prevents proper cooling of the parts affected. This sludge contains no free carbon, and can be washed off the affected parts with petroleum spirit, etc.

2. *Soap Sludge* frequently appears after transformers have been in service some time, and makes itself evident as a yellow or dark brown precipitate with a tendency to appear slimy. It is a "soap" with some oxidized hydrocarbon residue, and its danger lies in its great affinity for water which it may collect from the transformer oil.

3. *Carbonaceous Sludge*, due to breaking of an arc or corona in the oil. Such sludge, if produced by a low voltage power arc, is in the form of large flakes of free carbon of low specific resistance. A high tension arc, on the other hand, produces a fine amorphous carbon sludge which is less dangerous. Graphitic carbon is only produced when the arc is near enough to the surface of the oil, and is, of course, a good conductor.

The B.E.S.A. sludge test has been the subject of much investigation recently, and it requires very close adherence to detail and extreme care in carrying out to obtain accurate results. Fig. 75 shows the sludge testing apparatus built in accordance with B.E.S.A. specification for testing ten samples of oil simultaneously in the Metropolitan-Vickers Research Laboratory at Manchester. The main disadvantage of this test is the time it requires to obtain results, and it is interesting to note a form of quick test which has recently been put forward by Mr. W. H. Nuttall, of the Ioco Rubber and Waterproofing Co. This short test depends in principle on the fact that oils containing large amounts of unsaturated hydrocarbons (and therefore having a strong tendency to sludge) exhibit a much stronger interfacial tension towards water than that shown by oils which contain no unsaturated hydrocarbons. This is due to the affinity unsaturated hydrocarbons possess for water. The test consists of allowing a known quantity of oil to rise in bubbles through distilled water from a standard orifice. The drops are expelled from the orifices under a definite head of oil. Oil which contains large amounts of unsaturated hydrocarbons will rise through the water in small bubbles. The number of bubbles per unit volume of oil is claimed to afford a direct measure of the sludge properties of the oil.

The figures on page 150, quoted from Mr. Nuttall's results, indicate the wide difference between various oils which only differ within comparatively small limits when the sludge value is expressed in accordance with the B.E.S.A. specification. In these tests a 40 per cent solution of sulphuric acid was used instead of water in order to produce a wider difference in the results obtained with good and bad oils.

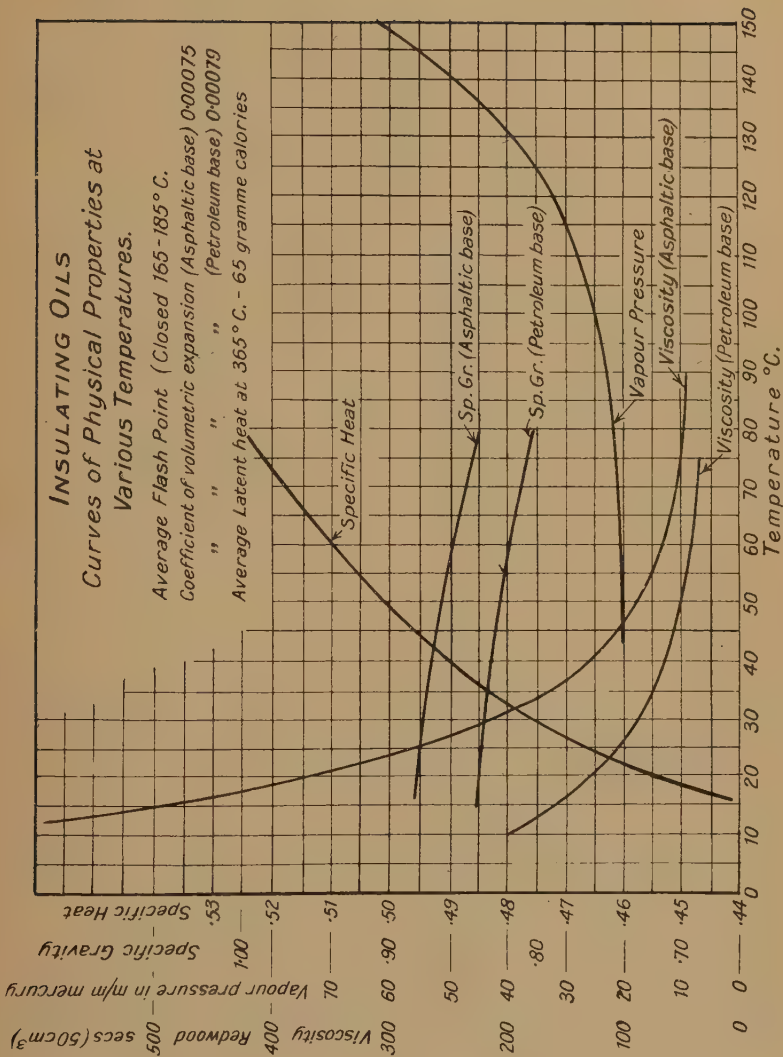


FIG. 23.—Physical Properties of Insulating Oils.

Oil No.	Drops per 100 cc. of Oil.	Drop Volume in cc.	Sludge Value by Ordinary Test No. 36.
1	802	0.1247	nil
2	731	0.1368	0.05%
3	752	0.1329	0.05%
4	798	0.1253	0.08%
5	1,616	0.0619	0.70%
6	1,733	0.0699	0.86%
7	1,790	0.0558	0.97%
8	1,742	0.0574	1.10%

Other methods of testing for sludge are employed on the continent of Europe. The generally recognized German method is described in *E.T.Z.*, 1922, No. 5, "Transformatoren-und Schalterole," by Dr. Georg Stern. It consists of introducing oxygen into the oil at 120° C. and then determining the tar content of the acid compounds thus formed. Detailed rules for making these determinations are given in the above-mentioned article.

A sludge test employed by Messrs. Brown Boveri, and described in the *Brown Boveri Review*, Vol. IX, No. 8 (Aug., 1922) is worthy of note, since it takes account of the colour of the oil and the effect on cotton immersed in the oil in contact with copper after prolonged periods of heating at 300 hours. The results from such a test are unquestionably valuable, but the duration of the test being 300 hours, places it outside the category of "routine" or "acceptance" tests.

Electric Strength of Insulating Oils.

The electric strength test has also been the subject of much investigation, and the B.E.S.A. standard $\frac{1}{2}$ in. diameter spheres have only been adopted after prolonged research on this subject. The curves in Fig. 24 are of considerable interest, as they afford a ready means of comparing the results obtained with different forms of gaps when testing oil. They also afford useful design data on flash-over clearances in oils. In this connection, it may be pointed out that the breakdown of oil can be influenced by the presence of foreign particles of fibrous matter, etc., which tend to line up between points of

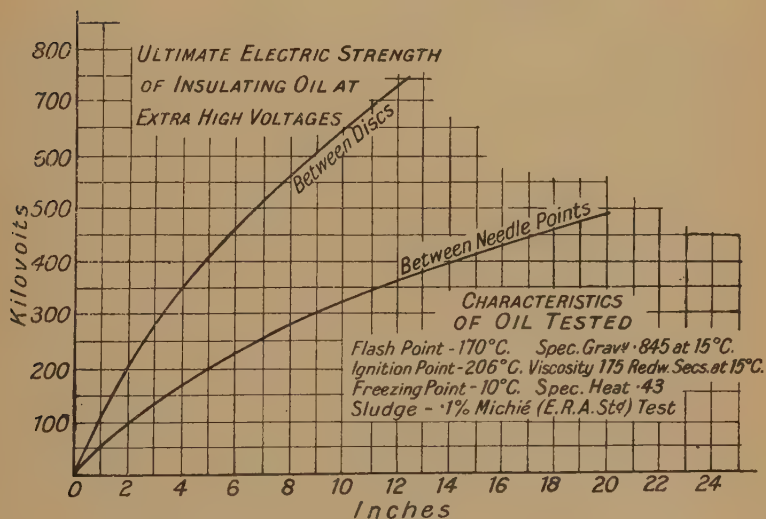
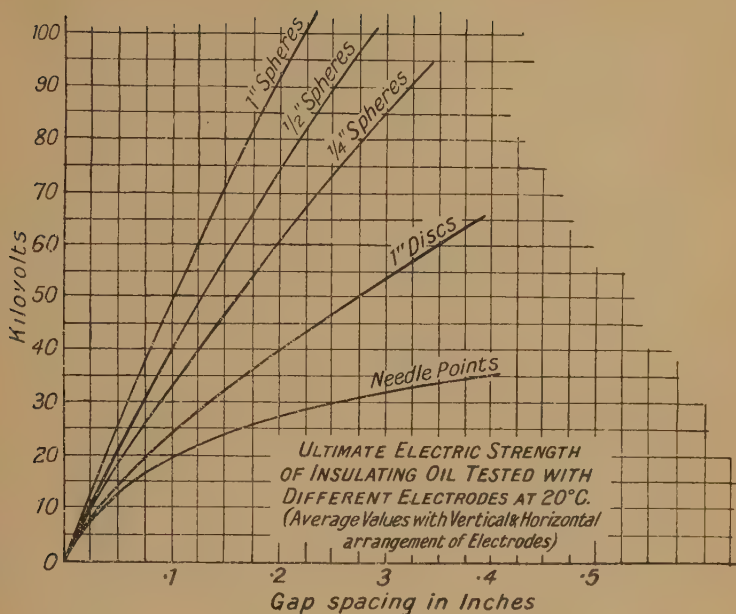


FIG. 24.—Electric Strength of Insulating Oils.

TABLE XVIII
PHYSICAL PROPERTIES OF INSULATING OILS REQUIRED TO FULFIL B.S.S. No. 148

Grade.	Sludge (Miche)	Loss by Evap- oration.	Flash- point (Pensky- Martens).	Viscosity (Redwood) at			Cold Test.	Dis- ruptive Strength	Acid Value.	Saponification Value.	Sulphur.	General.
				15·5° C.	20° C.	60° C.						
A (light)	per cent 0·1	per cent 2·0	170° C. ± 5° C.	≥ 175	≥ 145	≥ 45	- 5° C. ± 5° C.	kV 22	≥ 2 mg KOH	≥ 4 mg KOH	nil	The oil of each class shall be a pure hydrocarbon (mineral) oil, clean and sufficient-ly free from moisture or other matter likely to in-pure its insu-lating prop-erties and shall satisfy the require-ments set forth.
A (medium)	0·1	2·0	170° C. ± 5° C.	175-250	145-195	45-50	- 5° C. ± 5° C.	22	≥ 2 mg KOH	≥ 4 mg KOH	nil	
B (light)	0·8	3·0	155° C. ± 5° C.	≥ 175	≥ 145	≥ 45	- 5° C. ± 5° C.	22	≥ 2 mg KOH	≥ 4 mg KOH	nil	
B (medium)	0·8	3·0	155° C. ± 5° C.	175-250	145-195	45-50	- 5° C. ± 5° C.	22	≥ 2 mg KOH	≥ 4 mg KOH	nil	
C	—	3·0	155° C. ± 5° C.	≥ 300	≥ 250	—	- 20° C. ± 5° C.	22	≥ 2 mg KOH	≥ 4 mg KOH	nil	

It is under consideration to modify the above clauses in certain respects with the possibility of admitting a wider range of oils having, for instance, slightly lower flash-points and higher loss by evaporation, but the tendency is to increase the value of the disruptive strength.

opposite stress. This lining up will only occur, of course, so long as the foreign matter has a permittivity ^{higher} less than that of the oil. Foreign matter with permittivity ^{lower} higher than that of the oil is instantly thrown out of the dielectric field in the oil.

Standard Specifications.

Table XVIII shows the various grades of insulating oils covered by British Standard Specification No. 148.

CHAPTER XIII

RUBBER AND GUTTA-PERCHA

RUBBER, gutta-percha, and other products produced from the latex of certain tropical trees form the basis of a number of important insulating materials. Rubber itself is mainly used in the form of vulcanized hard rubber products, under the names of vulcanite, ebonite, etc. (See Chap. XIV.) Gutta-percha is extensively used as cable insulation. Amongst the less important latexes, chicle finds some use in insulating products.

Rubber.

The majority of cultivated rubber is that known as Para rubber, which is the latex of the tree *Havea braziliensis*. This tree, originally a native of Brazil, is now extensively cultivated in Ceylon, Malaya, Borneo, Dutch East Indies, and French Cochinchina.

The latex is tapped from the tree by making "V" shaped incisions in the bark, allowing the milk to run into a cup placed to receive it. The incisions in the bark are reopened every two or three days, during the tapping season, by paring off a thin shaving and thus reopening the latex bearing capillaries. The latex thus collected is then conveyed to factories, where it is sieved and bulked in tanks with other latex, after which it is treated with acetic acid in order to bring about coagulation.

The coagulum is then rolled into either—

1. "Ribbed Sheets," which are subjected to smoking in smoke houses for 10 to 14 days in order to "cure" them before exporting to the home markets.

2. "First Latex Crêpe," which is prepared by rolling the coagulum between deeply grooved rollers several times, thus producing crêpe, which is dried either naturally in large drying sheds with good ventilation, or by means of artificial hot air dryers.

In addition to Para rubber, a large amount of Manicoba and Ceara rubber is annually used for electrical purposes. This is the product of the tree *Manihot Glaziovii*. Another rubber latex producing tree of commercial importance is *Castilloa elastica*, growing in Central America and Peru, which furnishes excellent rubber, available on the market as Caucho or Peruvian Bull. African trees, including *Funtumia elastica* *Landolphia Klainci* (and other members of the same genus) have supplied large quantities of rubber in the past.

African rubbers are not as a general rule exported in the form of rolled sheet or crepe, but appear in solid lumps, known as Massai Nigger heads, Congo balls, Gambia balls, etc.

Generally speaking, the latex as it exudes from any of the above-mentioned trees contains from 35 to 42 per cent of actual rubber.

The chemical composition of rubber has been the subject of much research by many eminent authorities, and it is generally agreed that its formula should be C_5H_8 , or some multiple of the same. The formula $C_{10}H_{16}$ has been very generally applied. Some general properties of pure rubber are shown in Table XIX. The properties of vulcanized rubbers are too variable to be included, as they depend on the degree and method of vulcanization, and the nature of the fillers employed.

Pure rubber is used in the electrical industry in the form of so-called "Para Rubber Tape" for applying next to the conductor in cable manufacture, and in making cable joints, etc., in order to protect the copper conductors from the action of the sulphur contained in vulcanized rubber.

~ Something like 90 per cent of the rubber used in the electrical industry has been subjected to a process known as vulcanization, and it is from the discovery of this process by Goodyear, in 1839, that the modern rubber industry dates.

Vulcanization may be effected either by hot method (hot cure), in which the rubber is masticated with 8 to 10 per cent raw sulphur, or with antimony sulphide (Sb_2S_3), and afterwards subjected to a temperature of 130 to 140° C. for two or three hours, thus effecting the hardening known as vulcanization.

Certain high quality rubber products, including special tapes,

are compounded of sulphur and pure rubber without any other ingredients, but the great majority of rubber mixings contain organic fillers (paraffin wax, pitch, rosin, tar, and rubber substitutes made from linseed oil) and inorganic fillers (whiting, barium, sulphate, lithopone, French chalk, zinc oxide, antimony, sulphide of arsenic, mercuric sulphide, red lead, lead peroxide, ferric oxide, chromic oxide, graphite, and lamp black).

The physical properties of the finished article depend very largely on the nature of the filler which has been added. Obviously some of the above-mentioned fillers, although satisfactorily employed in the manufacture of non-insulating parts, cannot be employed where insulating properties are required.

In addition to these fillers certain ingredients known as accelerators are generally included in order to increase the speed of vulcanization. Litharge, calcium hydrate (slaked lime), magnesium oxide, and magnesium carbonate are the materials most generally used for this purpose.

The actual ingredients and quantities of the mixings employed are in general regarded as close secrets by the rubber manufacturing industry, and also very largely depend upon whether high-grade products are being produced or not. After being weighed out in proper proportions the material is thoroughly mixed by special mixing machines, and afterwards passed repeatedly through series of toothed and plain rollers, after which it is ready for rolling into sheet, extruding from dies as rods or tubes, or sending to the moulding department for the manufacture of moulded compositions. (See Chap. XIV.)

Cold vulcanization (cold cure) is brought about by treating the finished articles with sulphur chloride in dilute solution, with carbon bisulphide or carbon tetrachloride. This process, it may be pointed out, is not employed in the manufacture of electrical insulation materials.

Gutta-percha.

Gutta-percha is also a latex produced from East Indian trees, of which *Palaquium oblongifolium*, known to the Malays as "taban merah," and *Palaquium obovatim* ("taban puteh") are the most important.

The latex from gutta-percha can be collected from the tree

trunk, employing the same procedure as that employed in the case of Para rubber, but since the gutta-percha trees require 20 or 30 years before they come of tappable size, the modern practice is to prune the tree so that it is grown as a shrub, the leaves of which are collected, and the gutta is extracted from them by a process of crushing and treating with boiling water.

Gutta-percha at ordinary temperatures is not unlike leather, although less flexible, and possesses no elasticity. In the process of preparation it is boiled, cleaned, masticated, and strained, after which treatments it emerges as a dense material of a dark brown colour, becoming plastic when warm. It is absolutely impervious to moisture, but softens at temperatures of 40 to 50° C., according to the amount of natural resin it contains, and for this reason the material is not suitable as an insulator at high temperatures.

Gutta-percha becomes brittle on exposure to air and sunlight, but, when maintained under water, will retain its properties for an indefinite period. For this reason it is extensively used in the manufacture of nautical cables, and it is estimated that in connection with the world's submarine cable system, 26,000 tons of gutta-percha had already been

TABLE XIX
GENERAL PROPERTIES OF GUTTA-PERCHA

Name.	Geographical Origin.	Botanical Origin.	Sp. Gr.	Remarks.
Fine, hard Para (Wild Havea)	Amazon basin	<i>Havea braziliensis</i>	{ .92 to .96	{ Chemical Analysis of latex :— Water 55 % Rubber 38.5 % Proteins 3.0 % Resins 3.0 % Mineral Matter 0.5 % Hardens at 4° C Softens and becomes sticky at 50° C.
Ceylon Havea	Ceylon, etc.	<i>Havea braziliensis</i>		
Maniçoba (Ceara)	Brazil	<i>Manihot Glaziovii</i>		
Guayule	Ecuador, etc.	<i>Castilleja elastica</i>		
Gambia Balls, Massai Niggers Gambun Balls, Upper Congo, Mozambique, etc., etc.	African	<i>Landolphia Klainii</i> and other species of <i>L. Ficus elastica</i> , etc., etc.		
Gutta-percha		<i>Palaquium oblongifolium</i> and <i>P. obovatum</i>	.961	Softens at 60° C. Fuses before vaporizing at 190° C.
Chicle	Central America	<i>Achras sapota</i>		
Balata	Dutch Guiana	<i>Mimusops globosa</i>	.961	Softens at 50° C. Plastic at 100° C. Fuses at 150° C.
Jelutong	East Indies	<i>Dyera costulata</i> and <i>D. laxiflora</i>		

utilized up to the year 1921. As far back as 1859 and 1860, extensive tests were made by Fleming Jenkin, Latimer Clarke, Lord Kelvin, and other eminent authorities, on gutta-percha as an insulator, since even in those early days of the industry, it was realized that this material was better suited than any other for the insulation of submarine cables.

Some general properties of gutta-percha are shown in Table XIX.

The method employed in utilizing gutta-percha for cable insulation is referred to in Chapter V.

Chicle.

Chicle is the latex derived from the *Sapodilla* trees which grow in the mahogany forests of Yucatan, Campeche in Mexico, Guatemala, and in the northern part of British Honduras. This latex is the base from which chewing gum is manufactured, but the material is used to a limited extent to impart permanent flexibility to insulating varnishes.

Other latexes which are commercially utilized include balata, from the tree *Mimusops globosa*, and jelutong, derived from the trees *Dyera costulata* and *Dyera laxiflora*, indigenous to the East Indies, but these latter, although figuring in certain commercial products used in the electrical industry, are not employed as insulators.

CHAPTER XIV

MOULDED COMPOSITIONS

MOULDED composition insulators have long played an extremely important part in instrument and apparatus work, but their adoption in power machinery has been very slow when considered in relation to their potential possibilities, both as a solution of insulating difficulties and as a means of utilizing as fillers materials which are otherwise factory waste.

Moulded compositions fall into two general classes—

(a) **HOT MOULDINGS** produced with bonds which only become plastic under the influence of heat. This class includes—

1. Bitumen mouldings.
2. Rubber (ebonite) mouldings.
3. Mouldings made with natural resins and gums (including shellac).
4. Synthetic resin mouldings.
5. Celluloid and artificial celluloid mouldings.

(b) **COLD MOULDINGS** produced with bonds plastic at atmospheric temperature, but which solidify on exposure to the air or when brought into contact with mediums. This class includes—

1. Portland cement mouldings (including asbestos cement).
2. Mouldings made with natural clays as binders.
3. Mouldings made with sodium silicate as binders.
4. Mouldings made with casein and other organic adhesives as binders.

Bitumen Mouldings.

By far the greater number of the moulded materials used in electrical power engineering, such as for instance, switch handles, cable rack blocks, switch bases, terminal boards, etc., are made with bituminous binders, generally with the addition of small quantities of natural resins to give hardness and good

finish. The fillers used in this class of moulding include wood sawdust, pulverized paper, chalk, asbestos fibres, powdered marble, cotton waste, etc. The amount and nature of the filler employed depends on the service the article has to endure ; switch handles, for instance, are frequently produced with an organic filler, but for switch bases, terminal blocks, etc., asbestos fibre is largely incorporated in order to give at least a semblance of being fireproof. Bitumen mouldings have a low water absorption and may be used up to 99° C. Their electric strength depends very largely on the filler employed, and is found to vary from 50 to 300 volts per mil.

The process of manufacture is comparatively simple, the chief difficulty being in the production of suitable moulds. The bituminous material employed is mixed hot in a special pan, in which it is agitated by powerful impelling screws ; it is then bricketted into brickettes or rolled into slabs containing just sufficient material to produce the articles to be moulded. The brickettes (or sections cut from slabs) are put into heated moulds after being raised to a temperature in the neighbourhood of 100° C. on a hot plate, and are pressed to shape in power presses. Bitumen mouldings of this kind can be removed from the moulds immediately, and require no further curing. Contactor arc boxes and other parts containing a large percentage of asbestos fibre, but made with bitumen, are classed by the E.R.A. as " Class D " self-extinguishing mouldings.

Rubber Mouldings (including Ebonite).

Rubber mouldings, including so-called vulcanite and ebonite materials, are very extensively employed in high-grade instrument and apparatus work ; as for instance, in telegraph and telephone apparatus, radio equipment, measuring instruments, etc. Cheaper grades of adulterated ebonite are used in the manufacture of larger parts for heavy apparatus work. Certain special base rubber mouldings are also on the market, as for instance, lead filled mouldings for X-ray protection.

Rubber mouldings are non-hygrosopic and have a high dielectric strength, reaching 400 volts per mil in favourable cases. Special ebonite materials are produced which have



FIG. 25.—Moulded Composition Parts.
Manufactured by the Metropolitan-Vickers Elec. Co.

electric strength as high as 600 volts per mil, but these are too expensive to be regarded as commercial materials. Rubber mouldings should not be used where temperatures are likely to exceed 80° C.

In Chapter XIII some details are given concerning the production and preparation of rubber suitable for use in making rubber mouldings. The actual process of moulding ebonite parts is very similar to that employed in producing bitumen mouldings, except that the parts cannot be removed from the moulds until they are partially vulcanized or cured. After partial vulcanization it is, however, possible to remove the mouldings, and vulcanization is then completed by exposing the parts to steam pressure at a temperature of 130 to 140° C. for three to eight hours, varying according to the percentage of pure rubber incorporated in the mixture. In this process the temperature is raised slowly, taking one-half to three-quarters of an hour to reach its maximum.

Where it is required that the parts shall retain a certain amount of resilience, this property is retained by cutting short the vulcanization process.

Natural Resins and Gums used as Binders for Mouldings.

A number of mouldings are made employing natural resins and shellac as a binder. Such mouldings, although extensively used for a large number of purposes, including switch handles, telephone parts, automatic telephone relay blocks, etc., cannot be safely used at temperatures above 60 to 70° C. The material sold as "Insulate" by the General Insulate Co., of U.S.A., is an excellent example of a shellac base moulding. This particular material is claimed to have an electric strength of 300 volts per mil when made with a suitable filler. The process of manufacture is exactly similar to that employed in the production of bitumen mouldings utilizing the same fillers.

Synthetic Resin Mouldings.

Synthetic resin mouldings, using resins of the so-called "Bakelite" class, have played an extremely important part of recent years. Specimens are shown in Fig. 25.

Many complicated and high-class mouldings have been made for purposes such as magnetic distributors, multi-point jumper insulation, battery containers, etc., and have given the greatest satisfaction. These mouldings can be utilized at temperatures up to 105°C . (with organic fillers) and 150°C . (with inorganic fillers), and possess moderately good electric strength, varying from 80 to 200 volts per mil.

In general, they are very slightly hygroscopic and resist the action of acids and weak alkalis. The only serious drawback against their use is their inability to withstand the action of an electrical discharge without the "tracking" inherent in all phenol-aldehyde products thus far commercially developed. This defect naturally prevents bakelite mouldings being effectively used where exposed to an electric arc. The process of manufacture of synthetic resin mouldings is different from that employed for the other materials described above. The synthetic resin, in its intermediate or "B" stage of condensation, is mixed with wood flour, pulverized asbestos, or other appropriate filler, and is supplied in this form by manufacturers ready for moulding. The actual process of moulding consists of introducing a weighed quantity of the powdered mixture into heated moulds and pressing at a temperature of approximately 150°C . The resin fluxes at this temperature, and, uniting with the filler, forms a material which only remains plastic for a very few moments, since under the influence of temperature the resin quickly passes into its final condensation state and becomes hard and insoluble.

In the larger sizes of mouldings, the pressure must be retained from 10 to 15 minutes, and special provision has to be made for keeping the moulds hot during this time. It may be noted here that in the production of certain smaller types of synthetic resin mouldings, the raw material is made from fillers mixed into the synthetic gum in its liquid state, and is therefore in a plastic condition when introduced into the moulds.

The possibilities of the synthetic resin class of mouldings are hardly yet fully appreciated. One recent application has been in the production of moulded commutators, in which the commutator bars are moulded solid on to the commutator hub without the use of mica and steel "V" rings. In this case,

naturally, the tracking defect of the material necessitates that ordinary micanite insulation is employed between segments.

On the continent of Europe some very large parts, such as low voltage transformer bushings, wall bushes, etc., are made from pulverized waste insulation products bonded with synthetic resin of the phenol-aldehyde class.

Celluloid Mouldings.

Celluloid mouldings, including a number of similar products of a less inflammable type, are dealt with separately in Chapter XV.

Mouldings made with Casein and other Organic Adhesives as Binders.

Casein is the base used in a large number of moulded products very satisfactory for electrical work. Probably the best known of such products is Galalith. This material is produced by the action of formaldehyde on carefully matured plates, prepared from casein by precipitating a solution of casein in dilute caustic soda or ammonia with acid. The process of manufacture of Galalith consists in soaking the plates obtained as above in formaldehyde and afterwards drying, when they form a white translucent product similar to ivory. This product has been given the name Galalith and has a specific gravity of 1.31 to 1.35.

Mouldings are made from the material by warming in hot water, when they become plastic and can be pressed in moulds to any desired shape. A number of other similar casein products are produced by various patented processes, and have been applied as electrical insulators. Erinoid may be cited as a product of this kind, the insulating properties of which have been dealt with at length in the *Scientific Proceedings of the Royal Dublin Society*, Vol. XV (N.S.), No. 29; August, 1918.

Portland Cement Mouldings

(E.R.A. Class B, non-ignitable moulded products).

Portland cement mouldings as insulators come within the class of cold mouldings, and into this class fall the asbestos

cement products, including moulded arc shields and arc boxes. The most outstanding use of Portland cement as an insulator at the present time is in the manufacture of concrete type reactance coils (Fig. 26). In the manufacture of cubicles and switchgear partitions the material only plays the part of secondary insulation, and can hardly be regarded as an insulator proper.

Portland cement mouldings are not produced under pressure, but are cast in metal-faced wooden moulds.

Asbestos cement moulded parts, using asbestos fillers with Portland cement or lime as binders, are almost invariably produced under pressure.

All these materials are extremely hygroscopic, and consequently their electrical strength (minute value at 20° C.) is found to vary from 5 to 100 volts per mil.

In general the properties of these non-inflammable products containing asbestos are substantially the same for moulded parts as they are for the sheet materials dealt with in Chapter XVII. (See Class B, non-inflammable boards.)

Mouldings Made with Natural Clays

(E.R.A. Class A, non-ignitable moulded parts).

Soapstone clay, bentonite, and similar strong natural clays are frequently used as binders in the manufacture of high-grade non-inflammable moulded parts, as illustrated in Fig. 25. The use of these binders renders the product less brittle and less hygroscopic than those made with Portland cement. Such mouldings also show less deterioration under the action of an electric arc, and consequently are largely used for traction and

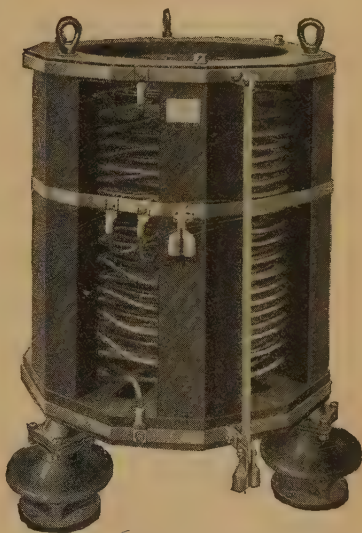


FIG. 26

A Concrete-Mounted Reactance Coil.

Made by the Metropolitan-Vickers
Electric Co.

industrial control work. Their general properties are shown in detail in Chapter XVII, under the heading Class A.

Mouldings Made with Sodium Silicate (Water-glass).

Sodium silicate has disadvantages as a bond, due to its tendency to produce hairy crystalline growth on the surface of mouldings in which it is used if exposed to dampness. Nevertheless, it is frequently used in conjunction with asbestos fibre to produce arc shield materials.

It may also be pointed out that some of the better grades of asbestos cement boards are treated with sodium silicate and carbonate of soda during the process of manufacture, in order to render them non-hygroscopic.

List of Products and Trade Names of Materials Recognized as Moulded Compositions.

AMIAITE. (See Chapter XVII.)

ARCOVITE. (See Chapter XVII.)

BAKDURA. A moulded composition made with synthetic resin and asbestos, pulverized paper, etc., by Micafil S.A., Zurich.

BAKELITE. A loosely-used word originally applied to the synthetic resin developed by Dr. Baekeland, but now used indiscriminately to describe both moulded compositions and varnish paper products, etc., in which the resin is used. Its wide use in this manner, without a qualifying word linked with it to signify whether "moulding," "paper product," or otherwise, is strongly to be deprecated.

CARBOLITE. A synthetic resin moulding material (not generally employing a fibrous filler) manufactured by the Russian Government factories at Orechova, near Moscow.

CELESTRON. A moulded composition made with a synthetic resin binder by the Siluminite Insulator Co., Ltd., of Southall, Middlesex.

CONDENSITE. A synthetic resin product made by the Condensite Co., of U.S.A. (Now part of General Bakelite Corporation.)

CORNITE. A name applied by Presspan and Electrical Insulating Material Manufacturing Co., formerly H. Weidmann, of Rapperswil.

CLEMATEITE. A moulded composition suitable for many purposes, produced by Le Matériel Isolant of Villeurbanne (Rhône).

CRYSTALATE. A weather resisting moulded composition produced by the Crystalate Co., Ltd., of Tonbridge, Kent, and used for third rail insulators, switch handles, bushes, etc.

DURABIT. A name employed by Kaupy & Schonmann, of Vienna, to describe hard rubber and similar products produced by them.

DURAX. A moulded composition made from paper pulp mixed with a moulding resin by Continental Isola-werken A.-G. Duren bei Birkesdorf.

DEXONITE. A hard rubber moulded composition produced by Dexine, Ltd., Abbey Lane, Stratford, London, E.15.

EBONESTOS. A name used by Ebonestos Insulators, Ltd., of Excelsior Works, Canterbury Road, London, S.E.15, to cover a range of moulded composition products, including heat resisting mouldings and heavy traction arc shields.

EBONITE. A general trade name, covering products made from hard vulcanized rubber. (See text.)

ELO. A synthetic resin produced by Birkby, and made into a variety of high quality moulded parts.

ERINOID. A product made in many colours from casein, by Erinoid, Ltd., Lightpill Mills, Stroud, Glos., England. Density, 1.34; softens at 85°C.; resists dilute acid. For electrical properties, see *Sc. Proc. Royal Dublin Soc.*, Vol. XV (N.S.), No. 29.

FENOLITE. A synthetic resin material sold by Giorgic Negri & Co., of Milan.

FERMIT. The name covers a range of moulded composition products produced by the Continental Isola-Werken A.-G., of Birkesdorf.

FIBRESTOS. (See Chapter XVII.)

FORMALITE. A synthetic resin moulded composition material developed by the Micanite and Insulator Co., of Walthamstow.

FORMULO. A moulded composition for resisting temperatures up to 350°C. made by Monte & Martini, of Milan.

FUTURIT. A moulded composition made by Kabelfabrik and Drachtindustrie A.-G., of Vienna.

GALALITH. See description in text of this chapter. This material is produced by International Galalith Gesellschaft Hoff & Co., of Harburg a.E.

GUMMOID. A moulded asbestos composition largely used for electricity meter bases, etc., made by Kabelfabrik and Drachtindustrie A.-G., of Vienna.

GUMMON. (See Chapter XVII.)

HIGHTENSITE. A rubber base moulded composition produced by Hightensite Ltd., of Normandy Street, Custom House, London, E.C.16.

HI-HEET. A synthetic resin moulding made with organic and inorganic fillers by the General Insulate Co., New York, U.S.A.

HIRCALITE. A moulded composition made in a number of grades by Hircalite Moulded Compositions, Ltd., of Kintore Works, Bermondsey, S.E.1.

HONDURITE. A moulded composition similar to Stabilite, with a cotton base and vulcanized binder made by Russells, Ltd., of Lands End Works, Rhodes, Lancashire.

INDURITE. A high quality moulded composition made from a synthetic resin and special fillers by W. Hunter & Sons, of 4A St. Andrew's Street, Edinburgh.

INSULATE. A product made with shellac as a binder and various materials, including mica, asbestos, barytes, woodflour, etc., as fillers. It is produced by the General Insulate Co., New York, U.S.A.

IVORIDE. A casein product (similar to Galalith), and claimed to be non-inflammable. Made by D. H. Bonnella & Son, Ltd., of 58 Mortimer Street, London, W.1.

JEWELITH. A synthetic resin base product made by Kunsthartz-fabrik Dr. Fritz Pollak, Vienna.

KALANITE. A name used by Callenders Cable and Construction Co. to cover a range of moulded compositions.

KOPAN. (See Chapter VI.)

LAPILAC. A moulded insulating material supplied in the form of sheets, rods, and tubes by W. F. Brown & Turner, Ltd., 2-3 Charterhouse Square, London, E.C.1.

LITHOLITE. A name used by Litholite Insulators, Ltd., to describe a range of moulded compositions, principally operating handles of switches, rheostats, etc., cable bushings, wireless fittings, telegraph insulators, etc.

LORIVAL. A synthetic resin product made in a number of grades by Lorival Manufacturing Co. (1923), Ltd., of 6 Lloyd's Avenue, London, E.C.3.

MONITE. A material similar to Galalith, obtainable from Presspahn and Electrical Insulating Materials Manufacturing Co., formerly H. Weidmann, Rapperswil, Switzerland.

MOULDENSITE. A synthetic resin product made at Sheffield by the Mouldensite Co. in co-operation with the Condensite Co., of U.S.A.

NORITE. A moulded composition claimed to be waterproof and oilproof, suitable for switch bar insulation, fuse carriers, etc., and made by the Norwest Electrical Manufacturing Co., Ltd., Motherwell, Scotland.

PAPIER MACHE. A general term describing a number of products moulded from paper pulp mixed with varnishes. Can be formed into a number of products, such as switch covers, fuse carriers, etc.

PYROSTATE. (See Chapter XVII.)

RADIOLITE. A composition product made by the Usines Dielectriques de Delle (Territoire de Belfort), France.

REDMANOL. Primarily the name of the synthetic resin developed by Redman in U.S.A., but applied by the Formica Products Manufacturing Co., of U.S.A., to a number of moulded products.

RHADOONIT. A moulded composition product originally made as a substitute for slate, but now available in any moulded form. Produced by Rhadoonit-Werke Kurt Wurzner of Weesenstein bei Dresden.

ROXITE. A synthetic resin moulded composition supplied by Northern Industrial Chemical Co., of Boston, U.S.A.

RUMIT. A moulded insulation used for small terminal blocks, plugs, caps, switch handles, etc., and produced by Rudolf Schmidt, Fabrik-electrischer Bedarfsartikel aus Isoliermaterial, of Leipzig.

SILUMINITE. (See Chapter XVII.)

SOLIDITE. A name employed by the Solidite Manufacturing Co., Ltd., of Mitcham, Surrey, to cover a range of moulded compositions made with bitumens, shellac, and resin binders.

STABILITE. A product containing cotton fibre and rubber, with suitable fillers extensively used in Germany.

SUPER-BA MOULDINGS. Synthetic resin mouldings made with Super-Ba synthetic varnish produced by Monte and Martini, of Milan.

TELENDURON. A general trade name applied to a number of products, sp. gr. 1.4-1.6, made by Thos. de la Rue & Co., Ltd.,

Walthamstow, London, E.17, and made in many grades (using different binders and fillers) as follows—

- Grade I. Mechanically tough and weather resisting.
- Grade II. Heat resisting up to 100° C.
- Grade III. Fire resisting up to 400° C.
- Grade IV. Acid resisting— H_2SO_4 at 1.2 sp. gr.
- Grade V. Alkali resisting—medium strength saline solution.
- Grade VI. Arc resisting when subjected to power arcs.
- Grade VII. Hot oil resisting up to 120° C. in insulating oil.
- Grade VIII. Special high power-factor (low dielectric loss) material.
- Grade IX. Synthetic resin mouldings for high-grade instrument work.

TENACIT. A name used by the Allgemeine Elektrizitäts Gesellschaft, of Berlin, to describe a range of moulded compositions. (See *A.E.G. Mitterlungen*, March, 1924.)

TERMIT. A moulded composition for temperatures up to 250° C. sold by Monte & Martini of Milan.

TROLITE. A moulded composition product produced in sheets and other forms by the Rheinisch Westfälische Sprengstoff A.-G., of Köln.

VITRITE. (See Chapter XVII.)

VOLKITE. A moulded rubber composition put on the market by Gebrüder Brunswig, of Hanover.

VULCANITE. A general trade name covering products made from hard vulcanized rubber (same as ebonite). (*Note.*—The name is also applied to a well-known roofing material of a fireproof nature.)

VULCO-ASBESTOS. (See Chapter XVII.)

WITTONITE. A moulded composition put on the market by the General Electric Co., of Witton, Birmingham.

CHAPTER XV

ARTIFICIAL CELLULOSE PRODUCTS

Artificial Silks.

ALTHOUGH many attempts to produce artificial celluloses in the form of silk were made prior to 1885, it was Chardonnet who first produced this material on a commercial basis in that year. Since that time many different processes have been evolved, which divide themselves into the following classes—

CHARDONNET OR COLLODION silks prepared from nitrated cellulose dissolved under pressure in a mixture of alcohol and ether. The solution is rendered nearly solid by passing through water, and is now generally denitrated to render it less inflammable. The liquid is passed through capillary glass tubes 0.08 millimetres diameter, from which it is drawn as a filament which rapidly coagulates in the air. Denitration is effected by passing through a solution of ammonium sulphide or other alkaline sulphides. Silks prepared in this way are also known as Pyroxylin silks. Lehner's silk is produced by a modified Chardonnet process employing a lower concentration of the Collodion, viz. about 10 per cent.

CUPRA-AMMONIUM OR GLANZSTOFF silks prepared from a solution of cellulose in ammoniacal copper oxide solution. The solution is prepared either by dissolving pure cotton in copper oxychloride and ammonia, or by preparing a cellulose hydrate and dissolving it in a solution of ammoniacal copper oxide. The filament is then squirted from capillary tubes under a pressure of 30 to 60 lb. per sq. in., through a solution of sulphuric or acetic acid or of caustic soda.

VISCOSE silks, prepared from a solution of mercerized cellulose in caustic alkali and carbon disulphide. This is prepared by grinding sulphite wood pulp into a coarse powder with caustic soda crystals. This product, known as "crumbs," is dissolved in carbon disulphide, producing viscose jelly, which is dissolved in water and left for a time to ripen, when it becomes less viscous. It is then ready for filtering under pressure, and

"spinning" by forcing through platinum die plates into concentrated ammonium sulphate or dilute sulphuric acid. A number of filaments are united on leaving the die plate to form the silk thread. The finished product is finally passed through ferrous sulphate and washed with dilute acid and water.

ACETATE silks, prepared by dissolving acetate of cellulose in chloroform, ethyl-acetate and alcohol, or acetic acid, and then coagulating by passing through water. The cellulose acetate may be prepared by a number of different methods, most of which include heating cellulose with acetic anhydride, glacial acetic acid, and sulphuric acid or methyl-sulphate. The silk thread is prepared by squirting from capillary tubes, as already described.

Other forms of artificial silks (although not celluloses) include Vanduara or gelatine silk, which is produced from animal gelatine by dissolving in water and extruding through suitable dies into a drying chamber, from which the filament passes through a formaldehyde solution to render it insoluble in water. Another artificial product has been produced in this manner with casein. (See Chap. XIV.)

Artificial silks have not been extensively used as yet for electrical purposes, except in a few instances for wire coverings or for the production of fine silk cloth for backing micanite products. This is probably due to the fact that up till recently the products obtainable have varied in consistency, and on the whole have not been comparable with natural silks. The art is, however, advancing so rapidly that it may be anticipated that artificial silks will soon be available with tensile strengths comparable with those of natural silks, and with moisture absorption properties which are even an improvement on those of natural silks. Reference to this material as a wire covering is made in Chapter V.

Some figures on the properties of various kinds of artificial silks are shown in Table XX, although, in quoting these figures, it is necessary to point out that they represent tests made on materials produced some years ago. The rapid strides which have recently been made in the production of artificial silks have doubtless resulted in the production of silks of much improved quality. The table will, however,

give some indication of the relative merits of silks produced by various processes.

TABLE XX
SOME PROPERTIES OF ARTIFICIAL SILKS

Class of Silk.	Spec. Grav. (Hassac).	Ultimate Tensile Strength.		Elastic- ity % (Mat- thews).	Moisture % in Air dry Sample (Süvern).	Ash % (Mitchell and Pri- deaux).	Average Thick- ness of Filament (Massot).	
		Kilograms/sq. cm. (Hassac).						
		Wet.	Dry.					
Natural Silk . . (average)	1.36	37.0	37.0	2.5	21.6	7.97-8.26	1.00	15
Chardonnet . .	1.52	2.2-3.6	12.0-1.59	0.93	8.0	10.37-11.17	2.23	28.8
Lehner . . .	1.51	1.5	16.9	1.43	7.5	10.71	—	35.4
Cuproammonium	1.50	3.2	19.1	1.64	12.5	10.04	0.18	31.4
Gelatine . . .	1.37	0	6.6	0.63	3.8	13.02	—	—
Viscose . . .	—	—	—	1.40	9.5	11.44	0.28	30.5

Celluloid, Xylonite, Etc.

Celluloid was originally produced from a low nitrated cellulose (pyroxylin), which, after being ground under water and dried by pressing in perforated containers, is mixed with 40 to 50 per cent of camphor and pressed at a temperature of approximately 130° C. During the final pressing at 130° C. the nitrocellulose becomes dissolved in the melted camphor, and celluloid is thus produced. Of recent years camphor has been replaced by a number of other materials, including esters of phenol, cresol, or naphthol; naphthaline, acetone, dinaphthylketone, etc., etc. Another process for producing cellulose, using the same raw materials with alcohol and ether added has been employed, but is limited in its application.

Owing to its inflammable nature, celluloid is not largely used in the electrical industry, but many less inflammable substitutes find extensive use as battery boxes, etc. These products are made very largely from cellulose acetate, cellulose formate, sulphacetates, and phosphacetates mixed with camphor or one of the substitutes for camphor above referred to. There are many possible combinations capable of producing so-called non-inflammable celluloid in this manner.

Amongst the most recently developed materials of this kind which have distinctly promising possibilities, Celastoid may be mentioned.

Celastoid is produced by British Celanese, Ltd., and is supplied in many forms for switch covers, terminal boards, wireless apparatus parts, etc. Its electric strength is in the neighbourhood of 400 to 600 volts per mil at 20° C. It is suitable for use at temperatures up to 75° C.

Sicoid, supplied by La Société Industrielle de Celluloid, of Paris, is a similar material.

List of Products and Trade Names of Materials Dealt with as Artificial Cellulose Products, Celluloid, Etc.

CELANESE. An artificial silk used for insulating wires, cables, etc., and made by British Celanese, Ltd., of Spondon, near Derby. It is claimed that this material is less hygroscopic and of higher resistivity than natural silk.

CELASTOID. An artificial cellulose product made in sheets and mouldings, etc., by British Celanese, Ltd., of Spondon, near Derby.

CELLON. A German term applied generally to cellulose acetate varnishes, etc.

SICALITE. An artificial cellulose product produced by La Société Industrielle de Celluloid, of Paris.

SICOID. A cellulose acetate product made by La Société Industrielle de Celluloid, Paris.

XYLONITE. A generally accepted name for celluloid products.

VISCOLITH. A product made by coagulating and drying a viscose solution, so that the hydrated cellulose separates out as a jelly and solidifies.

CHAPTER XVI

MICA AND MICANITE PRODUCTS

It is probably correct to state that mica is the most important insulating material used in electrical work.

The generic name " Mica " is applied to a number of minerals which crystallize in the monoclinic system—the crystals being frequently of the pseudo-hexagonal or pseudo-orthorhombic habit, and in many cases exhibit twin structure. These minerals, which occur chiefly in pockets in gneissic rock formation, group themselves into : (a) the mica group proper, (b) clintonite group, and (c) chlorite group ; but the only one of these groups which is of importance in the electrical industry is (a), the mica group proper.

This group includes the following commercially exploited micas—

(a) MUSCOVITE (WHITE) OR POTASH MICA, including the majority of Indian micas, and therefore the majority of the mica used in the electrical industry. This mica is also found in the Ural Mountains, Solovetsk (White Sea), Brazil, Kenya Colony, Switzerland, Sweden, Finland, U.S.A., and parts of Canada.

(b) PARAGONITE OR SODA MICA, found at Monte Campione (Switzerland), Tyrol, Ural Mountains, and in the U.S.A. at Delaware and in Pennsylvania. This mica is not used in the electrical industry.

(c) LEPIDOLITE OR LITHIA MICA, found at Mount Hradisko (Moravia), in Saxony, Ural Mountains, Cornwall, California and Maine, U.S.A. This mica is also not used for electrical work.

(d) ZINNWALDITE OR LITHA-IRON MICA, occurring at Zinnwald and Altenberg, in Saxony, is also of no importance electrically.

(e) BIOTITE OR FERRO-MAGNESIAN MICA, occurring on Mount Vesuvius, and also at Lake Baikal, in Siberia. This mica is of no use in the electrical industry.

(f) PHLOGOPITE OR MAGNESIA MICA. This is the so-called

amber mica, which occurs largely in Canada, and is extensively used in electrical work. It is also found at St. Gothard (Switzerland), and Pargas (Finland).

(g) LEPIDOMELANE OR IRON MICA, occurring in Germany, Ireland, Scotland, and Finland, but of comparatively little importance commercially.

From the above, it is clear that Muscovite and Phlogopite are the only two micas which are of importance as electrical insulators. Table XXI shows the general properties which characterize these two micas.

TABLE XXI
THE PROPERTIES OF MUSCOVITE AND PHLOGOPITE MICAS

	Muscovite.	Phlogopite.
Chemical Formula	$\text{H}_2\text{K Al}_3(\text{Si O}_4)_3$	$\text{HK}(\text{Mg F})_3 \text{Mg}_3\text{Al}(\text{Si O}_4)_3$
Chemical Composition (by analysis)—		
Silica (Si O_2)	45.2	40.8
Alumina (Al_2O_3)	38.4	26.9
Potash (K_2O)	11.8	12.7
Magnesia (Mg O)	—	7.6
Ferric Oxide	—	12.0
Water H_2O	4.6	—
Specific Gravity	2.76–3.0	2.78–2.85
Hardness, Moh's Scale . . .	2.8–3.2	2.5–2.7
Max. Temperature at which employable	535° C.	1000° C.
Permittivity (S.I.C.)	4.2–5.0	2.9–3.0
Spec. Resist. Megohms $\times 10^6$.	7–133	0.45–22
Electric Strength at 20° C. in volts per mil.	3250–6250	3700–4200
Percentage Water driven off at—		
450° C.	0.03	Note.—At temperatures lower than 900° C., Phlogopite Mica is un- affected 0.20 0.4–1.00
650° C.	0.06	
750° C.	1.69	
800° C.	3.29	
900° C.	4.20	
1100° C.	4.30	

Hardness, Elasticity, Etc.

As shown above, the hardness, according to Moh's scale, varies from 2 to 3, nevertheless, Muscovite, with a hardness

of 3, is too hard to employ as segment mica for commutators, where the mica is not undercut. Materials from various sources vary considerably in elasticity and toughness. Muscovite is very much less flexible than Phlogopite. The surface of individual splittings of Muscovite is smooth, whereas those of Phlogopite generally present a finely wrinkled surface, which for certain built-up mica work affords an advantage, as it assists to anchor the bond and prevents the splittings slipping over one another under pressure.

Water.

The temperature at which mica gives off water is much disputed, but is, nevertheless, of importance in some electrical work, especially where mica is used for heating elements, etc. It is also important to know this figure, so that it may not be exceeded when conducting incineration tests for determining the percentage of mica in various built-up mica products. The figures in Table XXI may be regarded as being substantially correct.

Impurities.

Mica crystals or splittings are frequently rendered useless for electrical work by the presence of impurities. Muscovite mica frequently contains microscopic crystals of beryl and needles of red, black, or green tourmaline; whilst red and brown garnet, zircon, felspar, quartz, and apatite are not uncommon. Sheets of Muscovite are often spotted and marked with metallic inclusions (as distinct from crystals), for the greater part consisting of magnetite (black), specularite (red), and hydrous iron oxide (yellow). The Phlogopite micas may contain microscopic prisms and needles of rutile, apatite, magnetite, etc. Quartz, iron pyrites, and other impurities also occur, not infrequently existing as layers or films of crystalline substances between the laminae. Such films make the mica incapable of being readily split.

It is the presence of these impurities, frequently only microscopic, which render unsuitable a very large number of the micas frequently offered to electrical manufacturers from new sources of supply.

Another very frequent defect, both in mica and in built-up micanite, is the presence of spots where the material has been crushed, either naturally or in the process of pressing. Such crushed spots possess extremely low dielectric strength.

Forms of Mica in Commercial Use.

The forms in which mica is used in the electrical industry are—

1. BLOCK MICA, i.e. small slabs or plates of the natural mica as taken from the mines. In earlier days of the industry block mica was extensively used for insulation between commutator segments, and pieces 6 in. wide by 12 in. to 15 in. in length were readily obtainable at reasonable prices. The great demand for segment insulation has, however, rendered the use of block mica for this purpose impracticable for economic reasons. Block mica is now employed only for special purposes, such as electrical condenser insulation. Even in electric irons, heaters, and similar work, block mica is now being superseded by special grades of built up mica (or micanite).

2. MICA SPLITTINGS. By far the largest amount of mica used for electrical insulation comes from the mines in the form of splittings. Splittings are sorted at the mines into various grades, depending on size, and to some extent upon flexibility. Unfortunately, the grades used by mica miners and brokers have not been universally adopted.

INDIAN GRADING. The standard Calcutta grading is as follows—

No. 1	grade consists of pieces of from 24	—35 $\frac{7}{8}$	sq. in. useful surface area
„ 2	„ „ „	15 —23 $\frac{3}{4}$	„ „
„ 3	„ „ „	10 —14 $\frac{1}{2}$	„ „
„ 4	„ „ „	6 —9 $\frac{7}{8}$	„ „
„ 5	„ „ „	3 —5 $\frac{1}{2}$	„ „
„ 5 $\frac{1}{2}$	„ „ „	1 $\frac{1}{2}$ —2 $\frac{7}{8}$	„ „
„ 6	„ „ „	up to 1 $\frac{3}{8}$	„ „

The figures for surface area do not refer to the *total* area, but to the sizes that each grade should produce. For instance, a No. 4 grade should enable rectangles measuring 2 in. by 3 in., 2 in. by 4 in., 1 $\frac{1}{4}$ in. by 5 in., 1 $\frac{1}{2}$ in. by 4 $\frac{1}{2}$ in., 3 in. by 3 in., 2 $\frac{1}{2}$ in. by 3 $\frac{1}{2}$ in., etc., to be cut. This grading is also employed for block mica. Nos. 1 and 2 splittings are very uncommon,

No. 3 being the largest practicable size for commercial purposes.

In addition to the various grades, splittings fall into various

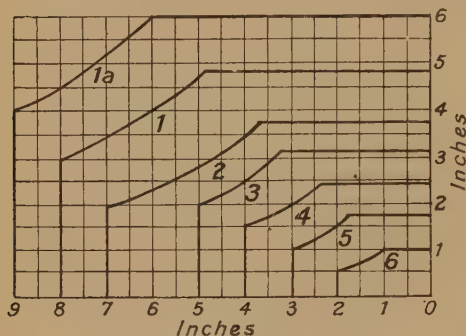


FIG. 27.—Grading of Mica
(Indian Standard).

classes, viz., extra special and special, pan packed and loose packed. Extra special and special splittings are always pan packed (not necessarily in circular cakes, some splittings being packed in square cakes). The term "extra special" denotes that the splittings are prepared from

a good quality full-sized block and are split very thinly and evenly. "Special" splittings are not quite so regular in quality or so full sized as the "extra special," but if the description is correctly applied, it should only be given to really good splittings. The term "pan packed" simply means that the splittings are packed in cakes, and does not indicate any particular quality. However, all pan packed splittings are prepared from more regular shaped block than loose splittings.

Loose packed splittings vary very much in quality, but, generally speaking, are

more irregular in shape than pan packed splittings. The price is always slightly lower. All very cheap splittings are loose packed.

CANADIAN GRADING. Canadian amber mica splittings are usually graded as follows: 1 in. by 1 in., 1 in. by 2 in., 1 in. by

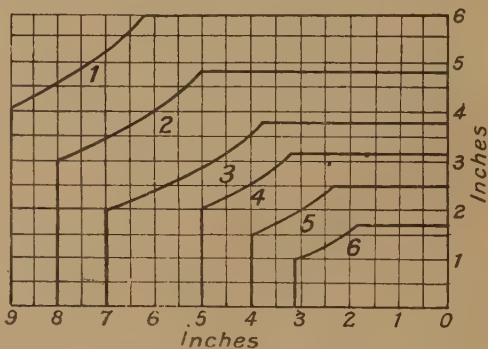


FIG. 28.—Grading of Mica
(Swiss).

3 in., 2 in. by 3 in., etc. These terms are more or less self-explanatory. The 1 in. by 1 in. grade is approximately equivalent to the Indian No. 6, 1 in. by 2 in. equal to the Indian No. 5½, the 1 in. by 3 in. equal to a No. 5, and the 2 in. by 3 in. equal to a No. 4. The great majority of splittings imported from Canada are the 1 in. by 1 in. grade, a much smaller quantity of 1 in. by 2 in. being used, while 1 in. by 3 in. upwards are comparatively rare. Canadian splittings are invariably loose packed.

Figs. 27 and 28 show some of the gradings which have been employed. Fig. 29 shows a grading system which has been introduced by one large user with the object of avoiding the confusion caused by the use of widely differing grade numbers. In this case, blue prints are supplied to the brokers when buying, showing the average size and thickness expected in any handful of splittings taken from a consignment at random. Moreover, the different grades of splittings are not given numbers which may be at variance with those in use at the mines, but are referred to by names, such as "segment splittings," "micafolium splittings," etc., etc. The thickness of mica splittings as they arrive on the market varies from ½ mil up to 2 mils, although splittings of 2 mils thickness are not sufficiently flexible to permit their use in the manufacture of flexible cells and insulating wraps. The edges of splittings should be knife trimmed and free from raggedness.

Certain larger grades of splittings are sold in so-called "books," which are simply blocks of mica which have been cleaved apart to form books of splittings.

Products Made from Mica Splittings.

The products made from mica splittings may be sub-divided as follows—

I. HARD OR SEGMENT MICANITE PLATE. Micanite plate for commutator segment work is built from—

- (a) Muscovite mica splittings for undercut commutators.
- (b) Phlogopite mica splittings for commutators, in which the segments are not undercut.

The size of splittings used are Grades 5 and 5½ (Indian grade). In the manufacture of this class of micanite, shellac

varnish bond is generally employed, care being taken to reduce the quantity of bond to a minimum. It is generally considered that the percentage of mica in well-made commutator segment

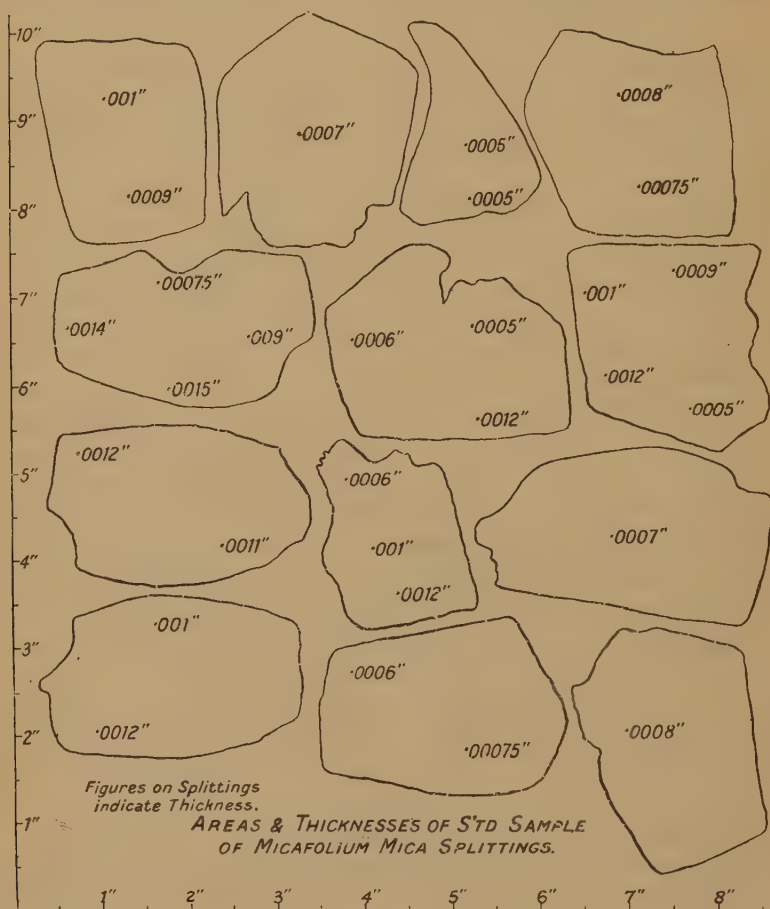


FIG. 29.—Mica Grading System.

plate should not be less than 95 by weight. Of recent years, the adoption of cushion-pressed micanite plate has gone far to compensate for unevenness in building up splittings into plate. (Cushion pressing is effected by the introduction during the pressing operation of a resilient material, such as is afforded

by two or three layers of fabric between the steel plattens of the press and the micanite).

Segment micanite is almost invariably subjected to milling and sanding operations in order to ensure its thickness being accurate to within the very fine limits rendered necessary in commutator work. The limits frequently demanded are as fine as plus or minus 1 mil on the average thickness of plates.

It may be pointed out here that "Micanite" was originally developed by the Mica Insulator Co., of U.S.A., for commutator segment work, since it was thought this material would be more suitable for the purpose than block mica. This development, it may be said, was not entirely based on economical considerations. Commutator work still remains probably the most important in which use is made of micanite, and even at the present moment authorities are far from being in agreement as to the most suitable methods to be employed in making and applying the material. There are engineers who contend that both segment micanite and the hot moulding micanite used in "V" rings should contain an excess of bond, which can be squeezed out when tightening up the commutators. As far as segment micanite is concerned, however, it is now generally accepted that the material should be hard pressed and contain an absolute minimum of bond. The material used for moulding "V" rings must, of course, contain 10 to 15 per cent of varnish bond, in order to get it to "slip" and mould readily, but it should not contain more. The idea of "squeezing" bond out of the micanite when tightening up commutators is not in general regarded as good practice. Many commutator failures are attributed to failure of the micanite due to its being either too soft or too hard, but there is little doubt that a large proportion of the failures in commutators are due to excessive tightening. In arch-bound commutators it is important that the assembled segments are not tightened too hard in the arch before the "V" is turned, as the stresses in the expanding copper afterwards distort the parts and are often the main cause of high bars. Tightening in building commutators should be done as the commutator cools after an initial baking and not before baking. Excessive pressures of more than 1,500 lb. per sq. in. in the projected area of the

inside coils or taper rings are also frequently the cause of commutator "insulation" failures.

Hard micanite plate is also used for coil and field spool insulation, washers for field coils, insulation barriers, etc.

2. HOT MOULDING MICANITE. Hot moulding micanite is generally manufactured from Muscovite mica splittings of a slightly larger size than those employed in the manufacture of segment micanite. Shellac varnish is also commonly used, but in considerably greater quantity than in the case of segment micanite. The percentage of bond by volume in hot moulding micanite varies from 10 to 25 per cent. This form of micanite is supplied in sheets which, when cold, are hard and inflexible. The material may, however, be rendered perfectly flexible by heating on a hot plate to a temperature of 105°C. to 115°C. , when it may be moulded into any desired form. The most extensive use of moulding micanite is in the manufacture of commutator "V" rings, for which it is cut into suitable segments and built up in successive staggered layers, which are afterwards moulded in special moulds to produce the "V" rings.

Other important uses are in the manufacture of slot linings, transformer rings, tubes, switchbar insulation, etc.

3. COLD MOULDING OR FLEXIBLE MICANITE. In the manufacture of flexible micanite, the grades 4 and 5 (Indian grade), Muscovite mica splittings are usually employed. The binders used consist of a special mixture of resins and gums with certain oils, usually including a small proportion of a non-drying oil, as for instance, castor oil. These binders are dealt with elsewhere. (Chap. VI, under the heading of "Mica Sticking Varnishes.")

Flexible micanite in many ways presents mica in its most convenient and economical form for electrical insulation, since it can be formed and bent to shape without the application of heat. It is extensively used for slot linings, special wraps, and coil insulation in electrical machines and extra high tension transformers.

4. MICAFOLIUM. The term "Micafolium" is now generally used to define a special product consisting of mica splittings built on a continuous length of strong kraft paper utilizing a

special binder. This material was originally developed for use in the Haefely wrapping machine. In its manufacture, only best quality flexible Grade 5 (Indian grade) Muscovite mica splittings are used, and they are built up on the kraft paper backing, using a special bonding varnish containing a large percentage of shellac. One, two, and sometimes three layers of splittings are employed, although with three layers difficulties are sometimes experienced in utilizing the material in the Haefely wrapping machine.

Micafolium is used extensively for large electrical machines, and affords an extremely convenient method of insulation, where percentage of mica in the final wraps is not required to be more than 30 per cent by volume.

5. MICA CAMBRIC, MICA TAPE, ETC. A large number of products are made utilizing high-grade flexible Muscovite, Grade 4 (Indian grade) splittings built up on various fabrics and stout insulating papers. Examples of these materials include—

(a) *Mica Silk*, which consists of Grade 4 (Indian grade) mica splittings built on to fine Japanese silk, using one of the above-mentioned mica-sticking varnishes as a bond. This material is generally afterwards slit into the form of tape, in order to facilitate its application to bars and windings of electrical machinery. Mica silk tape, when properly applied, satisfies I.E.C., B.E.S.A., and A.I.E.E. Rules as a Class B insulation, and therefore finds extensive use in the insulation of large turbo-alternators, etc.

(b) *Mica Cambric* is similar to mica silk, and is used to replace this where high percentage of mica is not of extreme importance and cost has to be considered.

(c) *Mica on Jap Paper*. Muscovite, Grade 4 (Indian grade) mica splittings are frequently built up on Japanese tissue paper with the idea of using the material as an easily applied insulation for the windings of large machines, in which it is important to secure an extremely high percentage of mica by volume. As in the case of mica silk and mica cambric, the bond used is a special mica-sticking varnish which will allow the product to remain pliable for a reasonable time. With continued exposure to air, however, all of these materials tend to lose their flexibility.

(d) *Pressboard and Mica, etc.* A number of special applications of mica splittings built up on pressboard, leatheroid, strong rope paper, etc., may be cited. In most cases, Muscovite mica is used with a shellac varnish bond. These materials are largely used for linings of special boxes, special barriers, etc., etc.

6. **HEAT-RESISTING MICANITE.** The development of heat-resisting micanite has progressed rapidly with the extended use of electricity for domestic purposes. Heat resisting micanites are made both from Muscovite mica and Phlogopite mica splittings. Generally speaking, the selected Muscovite mica splittings are used for low temperature work up to 450 to 500° C., but where this temperature is exceeded Phlogopite mica splittings are to be recommended, since this class of mica is capable of withstanding a working temperature of 850 to 900° C. without deterioration. The bonds used for the manufacture of heat-resisting micanite vary considerably, but, amongst others that have been successfully tried, silicate of soda, kaolin, and bentonite may be mentioned.

Somewhat naturally, the exact composition of these binding materials is kept as a trade secret, since the production of a satisfactory heat-resisting micanite is entirely dependent on the binder.

Machine Methods of Building Mica Products.

The most usual method of building mica products is the hand method, in which the splittings are individually placed in position by girls. This process is laborious, but, where reliable operatives are available, it probably results in the best product being obtained. Machine methods of building are, however, used in many factories for plate work. The most favoured machine method is the so-called mica tower, in which the splittings are "scurried" down a tower in blasts interspaced with a "peppering" of powdered bond. It may be pointed out that the arrangement at the head of the tower needs a very careful arrangement of baffles and air jets to obtain uniform results. The stacks of splittings and bond are very carefully removed from the base of the tower to ovens, where the bond is melted before it becomes

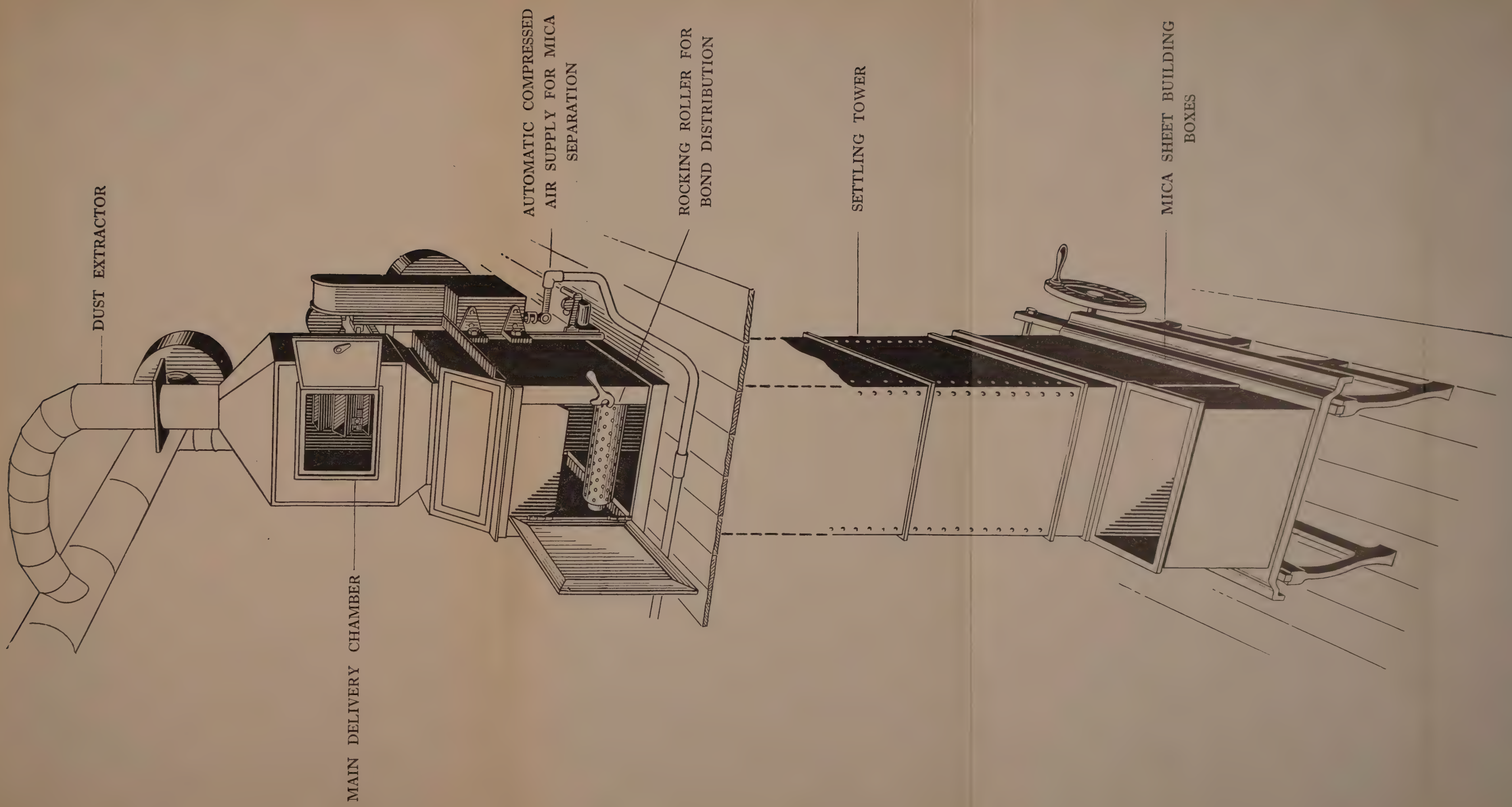


FIG. 29A.—Mica Tower.

dislodged, and the sheet is subsequently hot pressed in the usual manner. A mica tower is shown in Fig. 29A.

Amongst other methods of mechanically building micanite, one more or less successfully employed has been to deposit each layer of splittings by letting them drop an inch or more from the wire mesh bottom of a suction box against which they are drawn in from special splitting bins and retained so long as the partial vacuum is maintained. As soon as the vacuum is broken the splittings fall. They form a uniform surface, since they are more or less uniformly distributed on the suction box by the vacuum. (U.S. Patent No. 833,401, 1906. B. G. Lewis.)

Percentage of Mica in Mica Products.

In view of the definition of Class B insulation (see Chap. II) which has been given by the B.E.S.A. and other bodies, it is particularly important that some agreement should be reached with regard to the minimum percentage of mica allowable in Class B insulation, since there is little or no doubt much so-called Class B insulation is produced in which the percentage *by volume* of mica present is even less than 20 per cent. A minimum figure of 30 per cent is probably reasonable, but lower figures should not be permitted. It must be clearly

TABLE XXII
SHOWING CHIEF CHARACTERISTICS OF MICA PRODUCTS

	Sp. Gr.	Per- centage of Mica by Volume.	Electric Strength Volts/mil at 20° C.
Hard Micanite—			
(Muscovite)	2.0-2.4	70-80	800-900
(Phlogopite)		70-80	700-850
Hot Moulding Micanite			800-900
Flexible Micanite			600
Micafolium	1.5-2.4	20-25	—
Mica Cambric			700
„ Silk			—
Pressboard and Mica			350
Heat-resisting Micanite		—	—

understood these percentages are by volume, and therefore are much lower figures than percentages expressed by weight. A proposed standard method of making the test for percentage of mica is shown in Appendix I. Such a test will show approximately 40 per cent of mica by volume in a well-made stator bar wrap, and the figures given in Table XXII (page 185) are obtained by this method.

Substitutes for Mica.

Numerous attempts have been made to produce substitutes for mica and even artificial mica. As a rule such attempts have not been attended with great success. The majority of substitutes are produced by cementing flake, scrap, or pulverized mica with a suitable bond to produce a hard material—virtually a moulded composition. The bonds used are generally shellac varnishes, but recently attempts have been made to use bonds which are vitreous (ceramic) fluxes with low softening points. A material known as “Micallex” may be cited as a case in point. A genuine attempt to produce actual synthetic mica was made by I. J. Machalske, of Niagara, N.Y. (U.S. Patent No. 885,934 of 1908.) Work in this direction has also been done by Hautefeuille and St. Gilles, by von Chrustchoff, and by Doelter and Vogt. (See *Comptes Rendus*, Vol. CVII, 1888, p. 42.)

Standard Specifications.

No standard specifications for mica products exist at the present time.

List of Products and Trade Names of Materials Dealt with as Mica Products.

MICANITE. A trade name of a material originally built up from mica splittings, with a varnish bond, by the Mica Insulator Co. of U.S.A., but now generally adopted (except in U.S.A., where it is a registered trade name) by all insulation manufacturers to describe this product.

The terms “flexible,” “moulding,” “heat-resisting,” “segment,” etc., are used to describe micanites to which special properties are given by suitable varnish bonds, etc. In U.S.A. these materials are referred to as mica-plate, moulding mica, etc., to avoid the use of the registered name of Micanite.

MICAFOLIUM. A general name for mica splittings built in one, two, or three layers on strong paper (usually in continuous rolls).

MICARTA FOLIUM. A term used by certain Continental manufacturers to describe a product similar to micafolium.

MICANITE CLOTH, MICA CAMBRIC, "TOILE MICANITE," are all terms used to describe a product made from mica splittings, built on a cotton cambric backing. This product is frequently slit into tape form and described as "Mica-cambric tape," etc.

MICA SILK. A term used to describe an insulation used chiefly in the form of tape made from fine mica splittings built up on silk cloth, with the object of reducing the percentage of organic matter to a minimum in the insulated parts.

MEGOMIT. A special segment mica containing approximately only 1 per cent bond, produced by Meirowsky A.-G. Porz am Rhein.

AMBERITE. A trade name used by the "Fabrique Suisse d'Isolants," of Bretonbac (Soleure), Switzerland, to describe a number of micanite products, e.g. amberite indien, amberite canadien, amberite non fraise (heat-resisting), etc., etc.

MICALEX. A mica substitute made by bonding powdered mica scrap with a vitreous low melting point bond.

MICAFIL-G. Applied to tubes and special parts made from shellac coated paper and mica (i.e. micafolium) by Micafil A.G. Zurich-Altstettin, Switzerland. (*Note.*—Must not be confused with Micafil S. and Micafil B., which are varnish paper products.)

TURBOMIKA. A micanite for segment work made from Phlogopite by Jaroslavs Erste Glummerwarenfabrik, in Berlin.

CHAPTER XVII

ASBESTOS PRODUCTS

THE name "Asbestos" (from the Greek *ασβεστος*, meaning indestructible, unquenchable, eternal) is used to describe a number of minerals which resemble each other in that they are fibrous and to a greater or less extent fire-resisting, but are otherwise widely different. The majority of these minerals are silicates of magnesia and lime, but in many cases either the magnesia or the lime is partially replaced by a molecular equivalent of ferrous iron.

Two distinct groups of minerals are described as "asbestos," as follows—

1. AMPHIBOLE ASBESTOS (Horneblende asbestos). Including :

(a) Tremolite ($\text{CaMg}_3(\text{SiO}_3)_4$), white colour, occurring in Italy and Ural Mountains.

(b) Actinolite ($\text{Ca}(\text{MgFe})_3(\text{SiO}_3)_4$), green colour.

(c) Crocidolite $\text{NaFe}^{+++}(\text{SiO}_3)_2 \cdot \text{Fe}^{++}\text{SiO}_3$, blue in colour, occurring in South Africa. Crystals in monoclinic system with 56° angle between prismatic cleavages.

(d) Anthophyllite ($(\text{MgFe})\text{SiO}_3$). Crystals in orthorhombic system ; occurs in U.S.A.

2. SERPENTINE ASBESTOS. Including :

(a) Serpentine ($\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9$). Occurs as a rock which contains crystals of same composition to which the name Chrysotile is given. "Canadian Asbestos," used extensively in electrical industry, is Chrysotile. Colour : white, straw-yellow to brown, or blue.

(b) Palygorskite sub-group, which includes pilolite and various minerals of fibrous structure, generally with fibres "matted" together. "Mountain leather," "mountain cork," and "mountain wood" belong to this sub-group.

Although South African (Crocidolite) blue asbestos and also Italian (Tremolite) asbestos are extensively utilized commercially for heat insulation, and may also be used in the production of asbestos boards and mouldings, they are not generally accepted as affording the best fibres for the production

of tapes, fabrics, etc., and for this purpose chrysotile fibres are usually preferred. It should be pointed out that, since chrysotile asbestos contains 14 per cent water of composition, they only withstand temperatures of 300 to 500° C., whereas asbestos belonging to the amphibole group can be subjected to 1,000 to 1,200° C. before becoming seriously affected. The figures in Table XXIII show the comparative characteristics of the two groups of asbestos fibres.

TABLE XXIII
COMPARATIVE CHARACTERISTICS OF ASBESTOS FIBRES

Main Groups	Amphibole	Serpentine
Sub Groups	Crocidolite Tremolite Anthophyllite Actinolite	Crysotile
Colour of Fibre	Lavender Blue	Silky White
Length of Fibre	$\frac{1}{8}$ in. to 3 in.	$\frac{1}{8}$ in. to 4 in.
Specific Gravity	3.25	2.25
Nature	Harsh and Springy	Soft and Fine
Tensile Strength	Poor	Good
Flexibility	Poor	Good
Solubility in HCl	5% to 10%	65%
Critical Temperature . .	300° C.	400° C.
Iron Content	Up to 35%	Low
Uses	Sometimes used for filtering acids	Generally used for woven work
Country where mined . .	Italy Eastern Canada	Canada Russia South Africa

As an electrical insulator, asbestos is used in a number of forms—

1. Asbestos Paper.

Asbestos paper is used as a wrapper for insulating wires and rods and other parts subjected to heat, and also as insulation between turns in large machine windings. It has in the past been applied very extensively as a paper tape in the production of asbestos and single cotton-covered wires for the windings of heavily rated machinery. Certain synthetic varnish asbestos

paper boards, such as asbestilite and biasbeston, are produced from asbestos paper. Asbestos paper is made by an ordinary paper-making process (see Chap. III), and although it can be produced containing no vegetable fibre whatsoever, it very frequently contains some cotton fibres to give it strength. Papers containing no vegetable fibres have to be heavily sized to secure the necessary strength.

During manufacture, precautions have to be taken to eliminate metallic impurities from the pulp. This can be accomplished to some extent by a specially designed "sand table" on the paper-making machines, but certain manufacturers employ magnetic separators in this capacity. The conducting elements in asbestos fibres cannot, however, be entirely satisfactorily removed in this way, and chemical methods of treating the fibres with warm dilute oxalic acid and other reagents have proved very successful in eliminating the impurities and improving the insulating value of the material. The disadvantage of this treatment lies in the fact that it appreciably weakens the fibres mechanically.

Some properties of asbestos papers are shown in Table XXIII. These papers are not available in thickness less than 5 mils.

2. Asbestos Fabrics

(Including Tapes, Cords, and Yarns).

Long-fibred asbestos can be spun and woven into fabrics with considerable success, although a small percentage of cotton is generally permissible to give the necessary mechanical strength. Asbestos products can be classed as Class B insulation, provided the amount of Class A material is not sufficient to cause disintegration or appreciable mechanical weakening of the product at the temperatures permitted for Class B insulation. It has already been suggested (Chapter II) that 25 per cent of Class A material should be permitted in a Class B insulated product in which asbestos is the main item, and hence the 15 per cent of cotton frequently found in asbestos tapes should be permissible in the production of asbestos tapes and fabrics. There is considerable difficulty in spinning asbestos fibres to fine counts, and for this reason asbestos tapes finer than 10 mils in thickness are not commercially obtainable.

The majority of asbestos insulating tapes are supplied 15 to 17 mils in thickness. Asbestos tapes are frequently heavily calendered by the manufacturers to reduce their thickness, but this practice is bad, since it breaks the fibres unnecessarily. A light calendering is, however, desirable.

Asbestos yarns are also produced for braiding "fireproof" cables for kinema lanterns, flat irons, and similar work. Asbestos cloths are largely used in the manufacture of Bakelite asbestos boards. The choice of material for this purpose needs considerable care, since the bulk of asbestos cloth produced is intended for other industrial purposes and may have been wax treated, or, if for the manufacture of brake shoes, may contain copper wires. Such materials are useless for insulation work.

Asbestos cords are frequently used to insulate conductors passing through hot covers into ovens, etc. (generally in temporary work), and should be regarded more as a packing material for making hot joints tight rather than as an insulator.

3. Synthetic Varnish-Asbestos Products.

Synthetic varnish of the "Bakelite" class is used for making a number of products with asbestos, in the form of fabric, paper, or raw fibre as base material. The last named may be regarded as moulded compositions. (See Chap. XIV.) Products using fabric or paper as a base are gradually becoming popular as packing materials where mechanical strength is required at high temperatures. These materials can be regarded as Class B insulation and utilized up to 150° C., but, since they are subject to "tracking," they must not be employed where arcs are liable to come in contact with them. Some properties of these materials are shown in Chapter IX (Table XIV).

4. Non-Ignitable and Self-Extinguishing Boards.

The E.R.A. has selected the above title to cover a wide range of products in which asbestos is employed. The term "non-ignitable" is defined by them as applying to a material which, when heated under prescribed conditions, neither burns itself nor gives off inflammable vapours. "Self-extinguishing"

differs from non-ignitable in that it describes a material which may burn or give off vapour when heated, but which does not continue in a state of combustion when removed from the external source of heat. The E.R.A. classified these products as follows—

CLASS A. This includes non-ignitable asbestos boards and mouldings made of asbestos fibre and a binder of soapstone or other natural clay. The material withstands repeated exposure to an electric arc in air or to a flame of high intensity, and at the same time possesses relatively high insulating characteristics, both with regard to electric strength and resistance to surface breakdown. This class includes material used for arc shields on control apparatus and the like.

CLASS B. This includes non-ignitable asbestos boards and mouldings made of asbestos fibre and a binder of Portland cement, lime, or similar material. The material withstands repeated exposure to an electric arc in air or to a flame of high intensity, and at the same time possesses relatively high insulating characteristics, both with regard to electric strength and resistance to surface breakdown. This class includes material used for arc shields on control apparatus and the like, and is more brittle than Class A.

CLASS C. This includes non-ignitable asbestos boards and mouldings of a material that withstands repeated exposure to an electric arc in air or to flame of high intensity, but does not necessarily exhibit high insulating characteristics. This class includes materials suitable for a large number of structural purposes and for barriers in oil switches, cubicles, etc. The majority of so-called asbestos cements on the market fall within this class.

CLASS D. This includes self-extinguishing asbestos boards and mouldings of a material that withstands the application of an electric arc in air or flame of high intensity for very short periods only, but possesses high insulating characteristics. This class includes the bitumen-impregnated boards frequently referred to as “ Ebony ” grades), which are suitable for terminal boards, relay boards, switchboards, and the like.

CLASS E. This includes asbestos millboard and similar materials made from asbestos fibre, with the addition of a

small amount of flexible binder. The material, although non-ignitable, is seriously affected with respect to its physical properties when subjected to repeated exposure to an electric arc in air or to flame of high intensity.

Note.—It is to be understood that the classification of materials given above must be verified by the results of the tests outlined in this specification.

It should be noted that E.R.A. classification refers to both boards and moulded parts. The latter are dealt with in Chapter XIV.

Characteristic properties of the various materials covered in the above classification are shown in Table XXIV. It will be obvious that for traction and heavy duty controller purposes Class A material is the most satisfactory, although Class B boards are extensively used under the name of fully compressed asbestos slate, etc. Class C materials are too frequently unreliable in thickness to be of much use to electrical manufacturers as controller insulation, etc., but are very satisfactorily employed in the capacities mentioned in the classification above.

Fireproof materials of this nature have flooded the market during recent years under a great number of different trade names, with the result that much confusion has existed in the minds of users. As many as possible of these proprietary materials have been mentioned in the Appendix to this chapter, but (like moulded compositions) they are made by their producers in so many grades that purchasers are always well advised to specify just for what purpose they require the material they order.

5. Asbestos as a Covering for Magnet Wire.

Reference has already been made to asbestos paper tape used in conjunction with cotton yarn as a wire covering, and to yarn as a braiding for fireproof cables. Another method of applying asbestos as a wire covering exists, and is becoming increasingly popular. This method is described in detail in Chapter V, and consists of applying the asbestos to the bare wire in the form of a pulp, with some form of wax to improve its adhesion and prevent fraying.

TABLE XXIV—PROPERTIES OF VARIOUS CLASSES OF NON-IGNITABLE BOARDS AND MOULDINGS

It should be pointed out that, in addition to the materials falling under this classification, there are numerous other products on the market which closely approximate to one or other of the five classes recognized by the E.R.A., but which contain organic fillers and bonds.

	CLASS A.			CLASS B.			CLASS C.			CLASS D.			CLASS E.	
	Up to $\frac{1}{4}$ "	$\frac{1}{4}$ "- $\frac{1}{2}$ "	Over $\frac{1}{2}$ "	Up to $\frac{1}{4}$ "	$\frac{1}{4}$ "- $\frac{1}{2}$ "	Over $\frac{1}{2}$ "	Up to $\frac{1}{4}$ "	$\frac{1}{4}$ "- $\frac{1}{2}$ "	Over $\frac{1}{2}$ "	Up to $\frac{1}{4}$ "	$\frac{1}{4}$ "- $\frac{1}{2}$ "	Over $\frac{1}{2}$ "	$\frac{1}{16}$ "	$\frac{1}{8}$ "
Specific Gravity.	2.0	1.8	1.7	1.96	1.75	1.75	1.8	1.65	1.6	2.10	1.95	1.80	1.75	1.94
Compression Strength—lbs./sq. in.	10,000	8,000	6,000	8,000	7,000	6,000	8,000	5,000	4,000	13,000	12,000	11,000	—	—
Shearing Strength—lbs./sq. in.	2,500-3,750			2,500-3,250				1,500-3,000		3,500-9,500			4,500	3,750
Impact Test—ft. lbs.	0.8	1.3	2.5	0.5	1.0	1.5	0.3	1.00	2.0	1.5	3.5	8.0	Not applicable	
Electric Strength V/mil at 20° C. Min. Val.	*20	*15	*20	*20	*15	*10	< 10	< 10	< 10	75	50	40	70	35
Surface Breakdown Volts (normal cond.)	5,000-12,000			2,000-10,000				400-4,000		4,000-30,000			35,000	
Shrinkage Percentage on Volume.	0.6	0.3	0.2	1.8	1.6	1.4	1.0	0.8	0.5	In no case	> 0.4%		—	—
Swelling Percentage on Volume	1.25	1.0	0.8	1.25	1.0	0.8	1.25	1.0	0.8	0.8	0.6	0.5	—	—
Machining Properties.	Should be good			Fairly good—often brittle			Fairly good—often brittle			Good			Good	
Effect of Oil after 7 days' Immersion	Should be unchanged			Should be unchanged			Practically unchanged			Softens pulp or swells			Pulps	
Absorption of Water after 24 hrs. Immersion	12%	12%	11%	20%	16%	13%	26%	20%	16%	All cases less than 1%			67	60
Fuse Wire Test—condition after 10 tests	Should be excellent			Should be good			Should be good			Destroyed			Disintegrates	
Carbon Arc Test after— (a) 15 sec. exposure (b) 1-min. exposure	Slightly marked Small crater only			Unaffected Slightly pitted			Marked and may fuse Damaged			Ignites and burns			Destroyed (Fuses.)	
Meker Burner Test— (a) Value of K (b) Effect of Flame.	Infinity Unaffected			Infinity Unaffected			Infinity Unaffected			1.5-3.5 Swells, splits, ignites			Infinity Unaffected	
Radiant Heat Test—Ignition Temp. ° C.	No ignition			No ignition			No ignition			250-400° C.			No ignition	

* It is recognized that there are several materials on the market, the electric strength of which varies considerably from these figures. The author has frequently tested individual samples of Class A and B materials with electric strength well over 50 volts per mil.

† Between electrodes $\frac{1}{16}$ " diam. spaced $\frac{1}{16}$ " apart.

List of Products and Trade Names of Materials Dealt with as Asbestos Products.

AMIANITE. A special hardened asbestos filler moulding of high electric strength made by Presspahn and Electrical Insulating Material Manufacturing Co., formerly H. Weidmann, Rapperswil.

ARCOVITE. An arc shield material (E.R.A. Class A) produced by the Siluminite Insulator Co., Ltd., of Southall, Middlesex, and supplied in sheets or as special mouldings. This material has a comparatively high electric strength.

ASBESTOLITE.¹ A synthetic varnish-asbestos *paper* product supplied by the Swiss Insulating Works, Bretonbac (Soleure).

ASBESTONE. An asbestos-cement (Class B) produced by the British Uralite and Cellactite Works, Higham, Kent.

BIASBESTON. A synthetic varnish-asbestos *paper* product made by Micafil S.A., Zurich.

BRAVILITE. A name applied by Brazier & Co., of London, to a Class B asbestos-cement board produced by them.

CALBONITE. (See Chapter XIX.)

CARCOLA. A moulded asbestos product supplied by Micafil A.-G., of Zurich.

CELLACTITE. A bitumen impregnated (Class D) asbestos board produced by the British Uralite and Cellactite Works of Higham, Kent.

CORNITE. (See Chapter XIV.) Five grades of cornite may be regarded as non-inflammable products (E.R.A. classification), and include Cornite U. and Cornite F.A.S., which are high-grade arc shield materials.

CLEMATEITE. An asbestos-cement board produced by Le Matériel Isolant of Villeurbanne (Rhône).

DECOLITE. An asbestos-cement (Class B) produced by Bells United Asbestos Co. chiefly for flooring purposes.

DICKERLITE. A synthetic resin-asbestos moulded composition made by the English Electric Co., Ltd., used for arc barriers, etc.

ETERNIT. An asbestos cement made on the Continent. Largely used for building work and produced in many colours.

EVERITE. An asbestos-cement board (Class B and C) produced by British Everite and Asbestolite Works, Ltd., of Manchester.

FIBRESTOS. A non-inflammable (E.R.A. Class A) material produced by the Siluminite Insulator Co., Ltd., of Southall, Middlesex. Similar to Siluminite, but which has not been siluminized.

GUMMON. A compressed impregnated asbestos slate (Class D) produced by the Rheinisch Westfälische Sprengstoff A.-G., of Köln.

HIRCALITE. An asbestos-slate product (Class A) produced by Hircalite Moulded Compositions, Ltd., of Kintore Works, Grange Road, Bermondsey, S.E.1.

POILITE. An asbestos-cement (Class B) produced by Bells United Asbestos Co., chiefly for building and roofing purposes.

PYROSTATE. Similar to Amianite and made by the same firm, but withstands a higher temperature.

¹ Also applied to an asbestos-cement product supplied by British Everite and Asbestolite Works, Ltd., of Manchester.

ROBURINE. This is an impregnated asbestos board containing some pulverized mica, produced by the Cie Général D'Électricité in France.

SILUMINITE. A silicon-asbestos material made under high pressure and subjected to a special treatment known as siluminizing to render it moisture resistant. Made by the Siluminite Insulator Co., Ltd., of Southall, Middlesex, and extensively used for third rail insulators, switchboards, third rail protection, and in general where fireproof non-absorbent insulation is required.

SINDANYO. A high-grade non-inflammable asbestos product made in two grades, (1) plain Sindanyo (E.R.A. Class A material) and ebony grade (E.R.A. Class D material) by the Asbestos and Electrical Fittings Co., Ltd., of London.

TROLITE. (See Chapter XIV.)

UACOLITE. A trade name applied by Bells United Asbestos Co., Ltd., to a range of Class A, B, and C asbestos-cement boards. The Grade A and Grade B materials are specially adapted for electric arc shield work.

URALITE. An asbestos-cement board produced by the British Uralite and Cellactite Works of Higham, Kent. This material was originally made from asbestos with a binder of sodium silicate and bicarbonate of soda (Brit. Patent No. 6016 of 1902).

VITRITE. A compressed asbestos-moulded product made by Press-pahn and Electrical Insulating Material Manufacturing Co., formerly H. Weidmann of Rapperswil (Switzerland). Resists temperatures up to 500° C. and is used for starters, rheostats, electrode suspenders, etc.

VULCO-ASBESTOS. Similar to Amianite and made by the same firm, but better in electric strength and machining properties, used for brush-holder insulation, controller drums, etc.

CHAPTER XVIII

CERAMICS, GLASS, ETC.

INCLUDING PORCELAIN, EARTHENWARE, GLASS, AND VITREOUS ENAMELS

MODERN transmission line voltages of 100,000 volts to 220,000 volts are only rendered possible by improvements which have taken place during the past ten years in the design and manufacture of ceramic insulation—porcelain in particular. For the low tension work of earlier days the ordinary grades of porcelain and glass produced by reliable manufacturers was quite sufficient to give satisfaction, but to meet modern high voltage conditions, special grades of these materials have of necessity been developed. This development has only been possible by the closest co-operation between porcelain and glass manufacturers and the research engineers of the electric industry.

The materials which will be dealt with are—

1. Porcelain (including wet process, cast, and dry process porcelains).
2. Earthenware.
3. Glass.
4. Vitreous enamels.

Porcelain.

The art of porcelain making, like that of paper making, is one of the ancient arts which have been proved to have been understood by the inhabitants of China more than 2,000 years B.C. Possibly it is this ancient lineage of the art which is responsible for the conservatism of many porcelain manufacturers of to-day, resulting as it has done in the excessively slow development of high-grade electrical porcelain. Even to-day, many manufacturers apparently fail to appreciate the enormously improved product the electrical engineer is demanding.

In the manufacture of porcelain, the raw materials used are—

(a) PLASTICS. *Ball Clay*, a decomposition product of rock felspar.

China Clay, also a decomposition product of felspar, less plastic and strong than ball clay, but whiter in colour.

The proportion in which the two clays are used depends on the article being made, but for electrical work the complicated shapes required involve the use of a high percentage of ball clay, with its greater plasticity and strength.

(b) NON-PLASTIC. *Felspar*, an alkaline aluminium silicate which, for porcelain work, should be rich in potash. The felspar acts as a flux, partially dissolving the clay and producing vitrification.

Flint or Quartz, one of the purer forms of silica (SiO_2) which is included as an inert filler, not becoming entirely fused at the temperatures reached, and also not shrinking appreciably.

Process.

The felspar and flint are ground, and in the best practice superground, wet in ball mills to produce extreme fineness and also to improve homogeneity and electric strength in the final product. The clays are also mixed and stirred up with water to produce a thin slip, to which the finely ground flint and felspar are added, and the whole mass thoroughly mixed to as near as possible a perfectly homogeneous mixture. The amount and the temperature of the water employed are carefully controlled, so that the clay "slip" is of uniform consistency and density, ready for the subsequent process through which it passes.

The slip is passed under pressure through filters, which it leaves in the form of "filter cakes." In some cases these filter cakes are used directly without further working. More generally, however, the material is allowed a certain amount of ageing and then passes into a pug mill for final mixing. At this stage it is extremely important that the material should contain no air bubbles.

The forming of the porcelain parts is done by one of the following three methods—

1. WET PROCESS, in which the plastic material is moulded into plaster of Paris moulds and the surface not in contact

with the mould is then marked into the desired shape, either by machine forming or pressing. When sufficiently dried to be handled the part is then removed from the mould and smoothed up ready for glazing and firing. Another method of making wet process porcelain is to extrude the plastic material into tubes or bars. The pieces are then cut to the desired length and finished after the material is partly dry. Porcelain casings with rain sheds are made from cylindrical blanks, which are extruded and afterwards turned up to the desired shape in a lathe when the material has become sufficiently dry to be workable.

2. CASTING PROCESS, in which the plastic material is rendered more fluid by the addition of certain chemical salts and is cast in plaster of Paris moulds, from which the part is removed as soon as it has stiffened sufficiently to permit handling and finishing without distortion. Special and complicated H.T. porcelain insulators are made by this process. Plaster of Paris is used for moulds because it accelerates the drying of the porcelain body by its absorption of moisture.

3. DRY PROCESS, in which the filter cakes are dried and ground into a crumbly condition and then pressed into steel moulds. Such porcelains are of poor quality electrically, although they find an extension use in L.T. work.

After moulding, the porcelain is glazed. The glaze used is a mixture of the same materials as used in the body which becomes fused into a glass at the firing temperature of the porcelain. Various coloured glazes can be produced, but for electrical work white and brown are usually preferred. The essential feature in a glaze is that its expansion and contraction characteristics should be identical with that of the porcelain itself. If the contraction of the glaze is too great, it cracks, with many fine criss-crossed fissures known in the industry as "crazing." When the glaze has an excessively low contraction, large cracks will occur in it, and flakes will chip off. This defect is known as "shivering."

When the glaze has been applied, the moulded parts are subjected to preliminary drying and are then fired in special kilns or "saggers" for 50 to 70 hours at a temperature of 1,250 to 1,400° C.

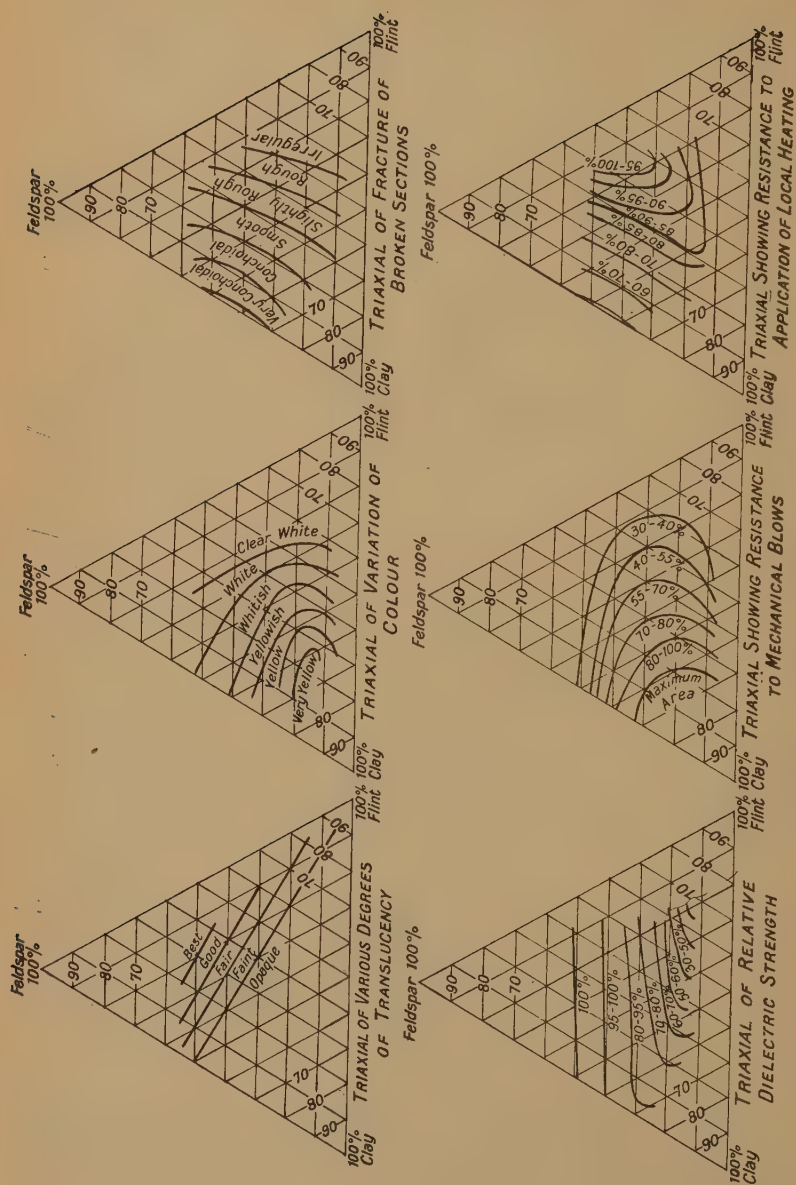


Fig. 30.—Porcelain. Triaxial Diagrams.

During this firing process the water is all gradually driven off as the sagger temperature rises. The glaze first melts, and subsequently the felspar also fluxes and dissolves the clay. The flint is also partially (but at ordinary firing temperatures not entirely) dissolved. This process is known as vitrification. Porcelains with a low flint content are more readily completely vitrified than those containing large percentages of flint, and consequently show a very conchoidal fracture. The smooth fractures are procured with equal parts of flint, felspar, and clay. Mixtures of this order, moreover, show relatively high electrical and mechanical characteristics. Fig. 30 shows tri-axial diagrams prepared by Gilchrist and Klinefelter (see *Elec. Journal*, March, 1918), which give a general indication of relative properties to be expected with different mixtures of the clay, felspar, and flint. In actual fact, small variations up to 5 or 10 per cent in the relative quantities of the three ingredients specified do not greatly affect the product so long as the formula, when once decided on, is rigidly adhered to by the mixers, and the raw materials are carefully checked for consistent good quality and uniformity. Similar close adherence to times and temperatures is also essential during baking if uniformity in the finished product is to be obtained.

Application of Porcelain in Electrical Industry.

A large number of firms are now specializing on producing high quality porcelain for electrical work, and with the present prospect of still greater development in E.H.T. transmission, the problems involved rightly deserve very close consideration. Dry process porcelain for L.T. work does not require much comment. It is extensively used for low tension terminal blocks, cleats, fuse carriers, ceiling roses, parts for lighting fittings and domestic appliances generally. The electrical and mechanical characteristics of these materials vary greatly, due to the presence on the market of large quantities of inferior material. It is the wet and cast process porcelains which are of prime importance, since all high tension insulators, shields for condenser terminals, lead in bushings, etc., are made by these processes.

Figs. 31 and 32 show typical examples of porcelain pieces of this kind. By far the largest demand is for transmission line insulators. Pin type insulators are in general use up to voltages of 66,000 volts, above which pressure the majority of engineers prefer to utilize suspension type insulators. The success of insulators of this kind (especially under wet weather conditions) is almost more largely a question of proper design of the insulator and its supports than of actual refinement in the material itself. Detailed considerations of design do not come within the scope of this book, but the following general notes may be of interest.

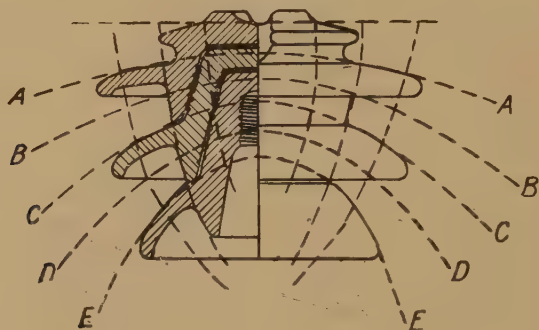


FIG. 31.—Pin Type Insulator.

Pin Type Insulators.

The effect of placing any insulating body such as a pin type insulator into the static field which exists between two conductors (as represented by a transmission line wire and an earthed insulator bracket) is to increase the stress in the air path at the surface of the conductor and at the surface of the insulating body, unless certain laws governing the proper shaping of the insulator are observed. It is a comparatively easy matter to design a porcelain of sufficient thickness to resist puncture, but the main problem is so to shape the air path that the flash-over voltage will be sufficiently high under all service conditions. Thus in modern insulator design it is generally considered of importance to make the surfaces of the porcelain "petticoats" or "sheds" conform to the lines of equipotential as far as possible. Fig. 31 will explain what is

meant by this statement. The dotted lines *A-A*, *B-B*, *C-C*, etc., depict the theoretical lines of equipotential. The full lines depict the actual cross section of a modern insulator. Practically all modern insulators are built up from a number

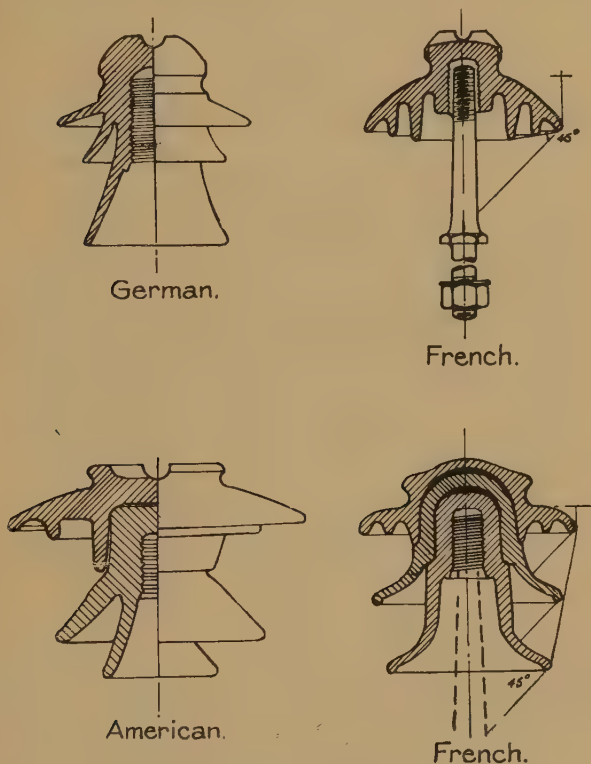


FIG. 32.—Typical Porcelain Insulators.

of sheds, as shown in the lower part of Fig. 32. Sheds are necessary to extend creepage surface, but on the other hand they must not be too numerous, since when they are closely spaced the air between them is easily ionized, with the result that preliminary discharges take place, thus short circuiting the dielectric field and resulting in flash-over at a voltage comparatively low in relation to overall dimensions. It must be remembered that the electric strength of air is four or

five times less than those shown for porcelain in Fig. 33. Surface leakage has also to be taken into very careful consideration, and the leakage on the different sheds in any insulator must be made as nearly equal as possible under working conditions. Some makers design the sheds so that the leakage resistance per shed is increased gradually from the head to

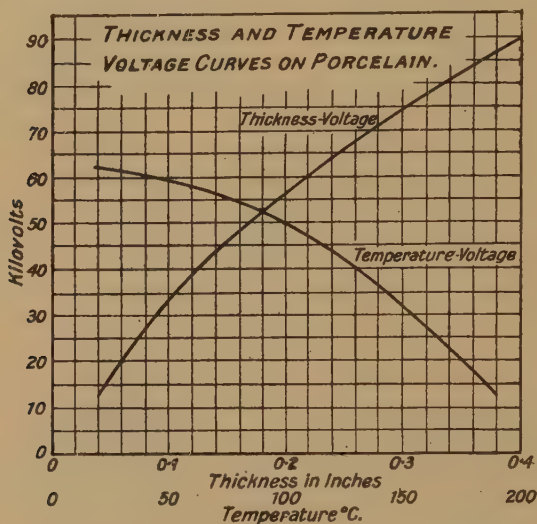


FIG. 33.—Characteristic Curves of Porcelain.

the centre shed, which is to allow for the lower sheds becoming dirtier in service than the top ones ; and thus, when rain falls on the top sheds (causing heavy leakage on these), the overall voltage distribution is maintained reasonably uniform. The capacity per shed should be calculated to be approximately equal when the insulator is clean and dry, and thus the distribution of voltage over the insulator should be even under all conditions, since this voltage distribution is dependent on capacity current and leakage current.

Ribs and sharp corners are to be avoided, since they are liable to produce uneven stress distribution during manufacture, resulting in fine cracks. In settling the design of porcelain insulators much can be done by theoretical considerations, but designs should be tried out experimentally to

check the dielectric field. A satisfactory method of doing this is to fit a piece of dry pressboard over a half section of the insulator, which latter must be fixed so that the plane to be explored for field distribution lies in the same horizontal plane in which the pressboard is put. Finely divided asbestos is

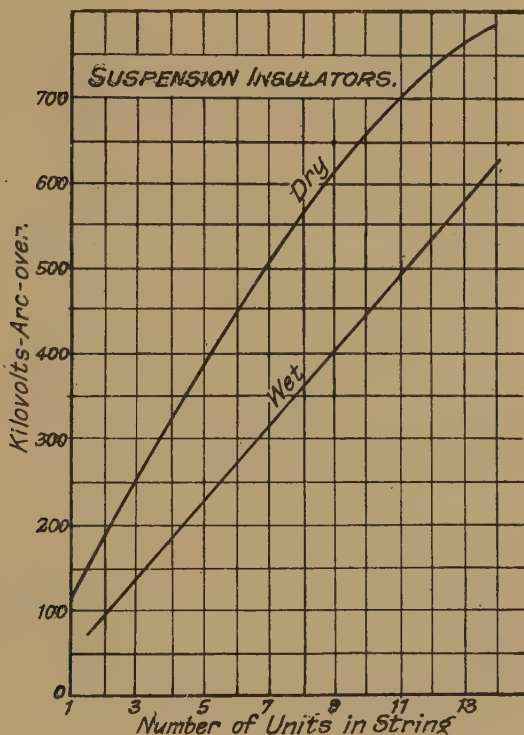


FIG. 34.—Insulator Flash-over Voltages.

then sifted over the pressboard. When the voltage is applied the pressboard is tapped until the asbestos particles take up their places in the field, thus creating a visual record.

Tests under high voltage are generally made on each separate shed of the insulator before assembly, and the flash-over per shed should be reasonably uniform. Figs. 34 and 35 show the wet and dry flash-over voltages to be expected on strings and

pillars respectively of 11 in. diameter embedded spider-type insulators.

Suspension Insulators.

What has been said with regard to the design of pin type insulators is equally applicable to suspension insulators, except

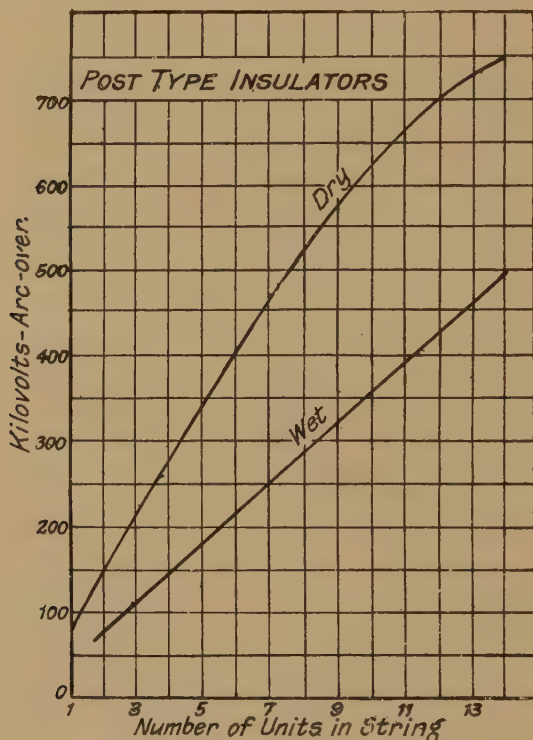


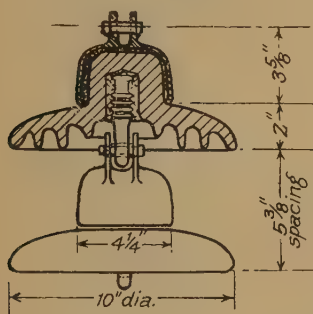
FIG. 35.—Insulator Flash-over Voltages.

that in the latter case the mechanical stresses are a combination of compression and shear instead of compression and bending. Experience has shown that comparatively simple designs of the porcelain parts produce better results than designs with ribs and corrugations. The surfaces are made sufficiently rough to grip the cement well simply by sanding.

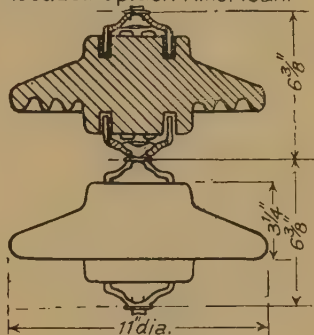
The main problem in the use of suspension type insulators is to secure a more or less evenly distributed potential gradient.

A string of insulators of the same dimensions, each with a capacity of, for instance, 0.000023 microfarads (which figure

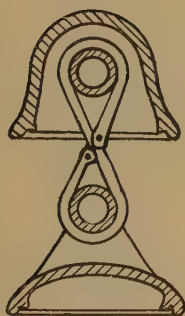
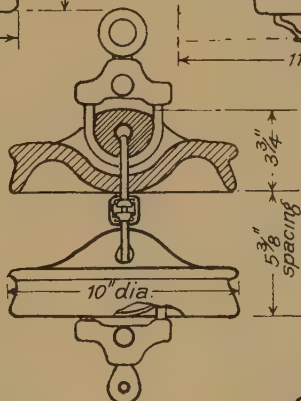
Cap and Pin.-English.



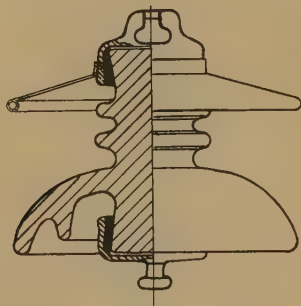
Embedded Spider.-American.



Link.-American



Link-French.



"Motor" Type Insulator.

FIG. 36.—Examples of Suspension Insulators.

may be taken as representative of a 10 in. cap and pin type insulator) will not allow an even potential gradient to be obtained over its entire length. In order to correct this

gradient and make it a uniform slope more nearly approaching the ideal straight line, several methods have been employed to readjust the capacity. The use of insulators of varying capacity

in the string constitutes an ideal solution, but has obvious disadvantages from a line maintenance point of view. This method is, nevertheless, used on certain extra high voltage lines.

Another method which has been used is to include additional metallic parts at the line end of a string of units.

Numerous other devices have been tried out to secure uniform stress distribution, including guard rings, guard cylinders, etc., and in some cases special arcing horns have been provided so that, if the string does flash-over, the arc is diverted in order to cause as little damage to the insulators as possible.

Figs. 36 and 37 show some of the types of insulator in common use. In all cases, however, the principle of even potential distribution over the strings has to be similarly adhered to. In the interlinked type, shown in Fig. 37, the capacity of the insulation is only approximately half that of the cap and pin type. This figure also shows the use of arcing horns. Special attention has been given during the last two years to the motor type insulator, shown in the previous figure. Although



FIG. 37.
Suspension Insulator.

these are for the most part produced from steatite composition, their design marks a new departure which is reported to be giving extremely satisfactory results.

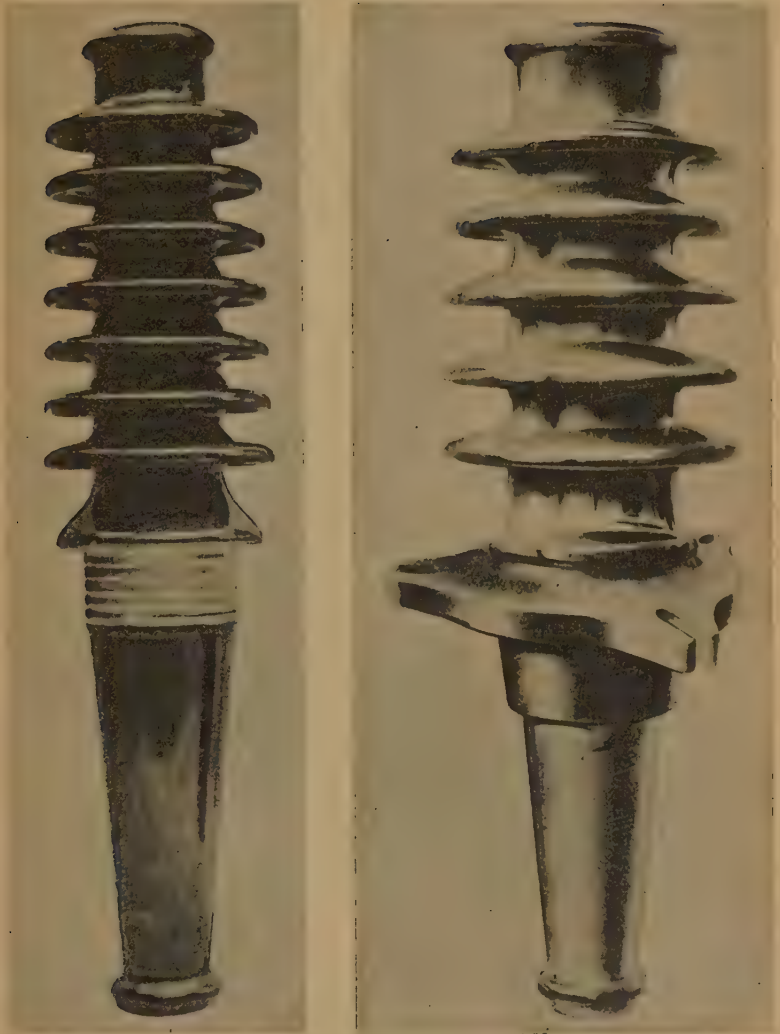


FIG. 38.—Solid Porcelain Bushings (75,000 volts).
(Made by La Porcelaine Haute Tension, Paris.)

E.H.T. Bushing Insulators.

Porcelain parts are used in the construction of E.H.T. bushings in at least three different capacities—

(a) Where the porcelain piece is used as an insulator itself without the addition of any other insulating materials.

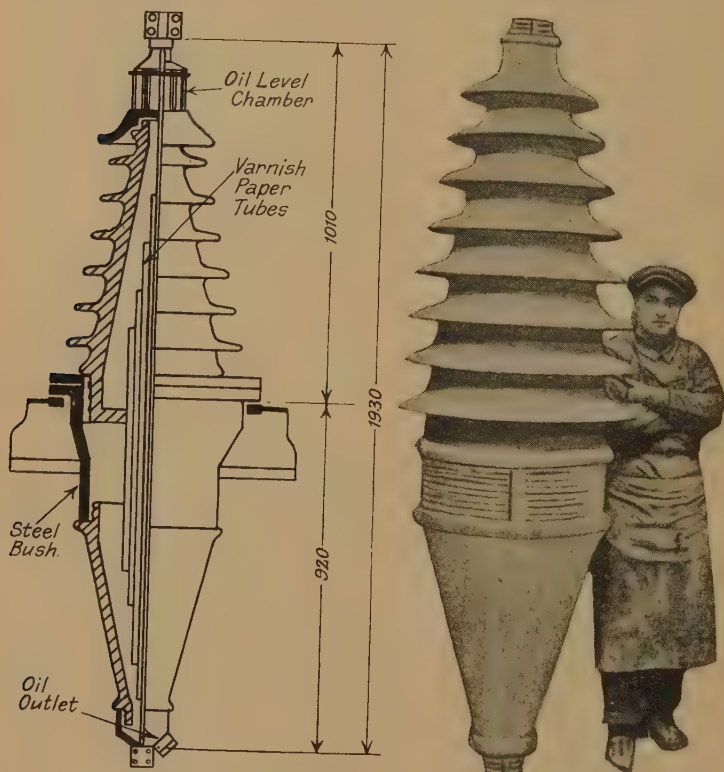


FIG. 39.—Oil Filled Porcelain Bushing.

Porcelain is used in this manner up to voltages as high as 75,000 volts. Fig. 38 shows such an insulator produced by La Porcelaine Haute Tension, of Paris, suitable for 75,000 volts.

(b) Where the porcelain is employed as a container for oil insulation surrounding a conductor which may or may not be otherwise insulated. Bushings of this type are extensively employed and are usually referred to as "oil filled bushings." The oil filler may be either a liquid insulating oil or a petroleum

jelly. Fig. 39 shows a cross section and general view of a typical bushing of this kind. Asphalt filled bushings also find extensive use.

(c) Where the porcelain is employed as a weather protection



FIG. 40.—Porcelain Weather Shield for 150,000 volt Condenser Bushing.

Made by La Porcelaine Haute Tension, Paris.

to a condenser type bushing. In this case the porcelain itself is not, strictly speaking, the insulator, and therefore its puncture value is of comparatively small importance provided its "flash-over" features are good. A brown glazed porcelain is frequently employed for this work. Such bushings frequently have the space between the porcelain "shed" and the actual

condenser bushing filled with an asphalt. Fig. 18, Chapter IX, shows the cross-sectional view of a bushing of this kind made by the Metropolitan-Vickers Electrical Co., Ltd., and Fig. 41 shows a typical single-piece weather shield made by La Porcelaine Haute Tension, of Paris, for a 150,000 volt condenser bushing. 40

Earthenware.

Earthenware is a term used to describe a large number of different kinds of pottery, all of which consist of a porous body (or biscuit) covered with a glaze. These materials are produced from mixtures of clays, glass forming fluxes and refractories with suitable colouring matter in much the same manner as porcelain, but are generally inferior in quality to the latter. Earthenware is, however, not infrequently used as a substitute for cheap porcelain. One of the largest uses of earthenware as an insulator is as containers in liquid starters, as basis for resistances, etc. Very large quantities of earthenware are also employed as ducts for electric cables, although in this capacity they may hardly be regarded as insulators.

Glass.

Glasses are described by Searle (see Martin's *Industrial Chemistry*, Vol. II) as, "bodies which have been cooled somewhat rapidly from a high temperature at which they existed in the molten state, so that on cooling they remain amorphous in form and partake of the nature of solid fluids."

Most of the glasses used in electrical work are made by fusing silica (sand) with two bases, one of which is usually soda or other oxide of a divalent metal. Oxides of barium are used to produce some excellent glasses for technical work. Boro-silicate glasses containing baryta and lime, but free from other alkali, have been found by Schott (Schott and Abbe, *Glasindustrie in Jena*, 1909) to have particularly high insulating properties, and such glasses resist chemicals many times as well as ordinary commercial glasses. They are also capable of withstanding sudden temperature changes. "Durex" glass, Gerate glass, and the Schott Verbundglas, all produced at Jena, are typical examples of glasses of this kind. In 1915 the Institute of Chemistry published a number of formulae in

order to assist British manufacturers to reproduce glasses similar to those made at Jena.

The actual process of manufacture consists in pulverizing the raw materials, weighing, mixing, and finally melting in special pots. The melting takes from 10 to 12 hours to complete, during which time considerable quantities of gas are given off and impurities rise to the surface as a scum, which can be readily removed. Before removing from the pot the molten glass is raised in temperature and refined or "planed" by introducing potatoes, apples, or similar vegetable matter into the pot and stirring. This has the effect of producing further volumes of gas, which agitate and refine the molten mass. On removal from the pot, the glass can be worked into any desired form. Since so many materials, varying in specific gravity from 2.25 to 6.5, are described as glass, it is difficult to give any general data on the physical properties of these products.

Glass for Pin and Suspension Insulators.

A number of firms are now producing glass insulators of the pin and suspension type for overhead transmission lines. These insulators are similar in design to those made from porcelain and are claimed to give equally good results in service.

Accumulator Containers, Etc.

Amongst the electrical uses to which glass is put, the manufacture of large accumulator containers is probably the most important. For this purpose an acid-resistant glass is essential.

Glass in the Lamp Industry.

In the production of electric lamps, valves, X-ray tubes, and in electrical apparatus and electromedical work generally, glass finds an extensive use. The forms of glass employed are highly refined and special, and therefore will not be dealt with further in this work, particularly since in this work the glass is not used primarily as an insulator.

Quartz Glass or Fused Silica.

Fused silica articles find a use in certain electrical apparatus as, for instance, pyrometers and thermostats. This material is produced by fusing pure quartzose sand in an electric furnace.

The fusion is not generally complete, so that articles made from this material usually present the appearance of being cloudy and rough surfaced, being permeated with numerous bubbles. Fused silicates, although they resist water and acids, are extremely susceptible to the attack of alkalis and metallic oxides. They soften at $1,500^{\circ}\text{C.}$, have a specific gravity of 2.08 to 2.22, and the extraordinarily low coefficient of expansion of 0.5×10^{-6} (between the limits 0°C. and $1,100^{\circ}\text{C.}$).

Spun Glass.

Spun glass is the name given to fine glass thread produced by simply drawing out the material when in its plastic state. Filaments finer than silk can be produced in this way, and may be worked up into fabrics, tapes, etc. This application may have some use in electrical insulation work of the future. The glass used should be one which remains plastic over a long temperature range. Lead glasses are suitable in this respect, but probably have other disadvantages from an electrical point of view.

Vitreous Enamels.

Vitreous enamels have been experimented with as insulating materials, but with no success as yet sufficiently appreciable to render the process one of real commercial application, except for such work as insulating metal tubes to carry wound resistances, etc.

Standard Specifications.

The British Engineering Standards Association has issued a specification (No. 137, 1922) covering porcelain insulators for overhead power lines (3,000 to 150,000 volts).

The A.S.T.M. has also issued a specification for testing porcelain (No. D116-2T, Tentative methods of testing electrical porcelain).

List of Products and Trade Names of Materials Dealt with as Ceramics.

FIREITE. A heat-resisting unglazed porcelain produced by the Electric and Ordnance Accessories Co., of Hanley.

PRESSOLITH AND SILLIMANITH. Earthenware-porcelain products supplied by G. V. Hertsen, of 246 Corporation Street, Birmingham.

CHAPTER XIX

SLATE AND MARBLE

1. Slate.

SLATE plays a very large part in the electrical industry, since it is the main material used for switchboard work. It is a fine-grained rock, which has more or less perfect cleavage, permitting it to be readily split into thin, smooth sheets. Slates differ widely in colour and have a considerable range in chemical and mineralogical compositions, and, in consequence, a number of the slates offered by quarries for switchboard work are unsatisfactory. For this reason, electrical manufacturers should hesitate to adopt new sources of supply for slate without thoroughly investigating the properties of the material offered.

Excepting certain rare slates of igneous origin formed from volcanic ash or igneous dikes, slates have originated from sedimentary deposits consisting largely of clay. Other minerals originally present with the clay in limited quantities include quartz, mica, zircon, compounds of iron, lime, and magnesia, carbonaceous matter, and some silicates. Such materials were deposited in bodies of water, and through changing conditions of erosion and deposition, successive beds may have differed considerably in composition. Other materials, such as calcium carbonate or sand and gravel, may have been deposited over the clays, and the pressure of the superimposed materials may have gradually consolidated the clays into bedded deposits of shale such as are found in many places. A shale is a laminated rock consisting essentially of clay, but it does not possess the splitting properties of slate.

Many shales, however, have been subjected to intense metamorphism. The mountain building forces ever at work in the earth's crust may crumble and fold the shales under the influence of intense pressure and high temperature. By such processes shales are transformed into slates. The intense pressure changes the orientation of the mineral grains, which

normally lie parallel to the bedding, causing them to assume parallel positions and lie at a more or less definite angle to the direction of pressure. At the same time, high temperature acting with the pressure tends to alter the constituent minerals, changing them to new minerals, such as mica, quartz, chlorite, magnetite, graphite, tourmaline, and various others; the mica, quartz, and chlorite usually predominating. The parallelism of the mineral grains results in that tendency to split with ease in one direction, which has been termed slaty cleavage. When the metamorphic process has reached such a stage that slaty cleavage is pronounced, the rock is termed a true slate. The rock is usually folded and contorted, and in consequence, the slaty cleavage may intersect the bedding planes at various angles.

TABLE XXV
PROPERTIES OF SLATE, MARBLE AND SWITCHBOARD MATERIALS

	Sp. Gr.	Electric Strength Volts per 1" thickness	Surface Electric Strength 1½" distance	Percent- age Water abs. 24 hrs. immer- sion.	Percent- age Oil abs. 6 hrs.	Izod Impact ½" thick ft. lb.	Tensile Str. lbs. sq. in.	Crushing lbs./ sq. in.
Slate	2.7-2.9	8,000	—	0.196	0.031	—	3,625	10,000
Soapstone		25,000	—	—	—	—	—	6,900
Marble	2.6-2.8	65,000	—	0.26	0.291	—	—	13,000
Ebony Asbestos Wood	1.9-2.0	56,000	25,000	0.062	0.191	5.0	2,060	15,000
Ebony Syndanyo . . .	1.5	33,000	18,000	0.342	0.2	5.0	1,400	12,500
Siluminite	1.8	33,000	8,000	0.148	0.074	2.0	—	—
Pixtonet	2.0	94,000	27,000	0.005	No effect	3.5	—	—
White Syndanyo . . .	1.4	8,000	8,000	20.0	No effect	4.2	2,000	22,400
Arcovite	1.1	12,000	15,000	32.0	No effect	1.5	1,300	—

The process of alteration of the original minerals may be only partial, resulting in a slate having as its chief constituents clay, mica, and chlorite. Such a slate is termed "clay slate." The process may, however, be carried further, until little or no clay remains, the chief constituents being mica, quartz, and chlorite. As chlorite is also flaky and mica-like in character, such a rock is termed "mica slate." Mica slates are more resistant to absorption, and therefore more enduring than clay slates. They constitute the chief supply of commercial slate.

Continued intensive metamorphism of a mica slate produces more complete recrystallization in coarser grains, and develops in the rock a schistosity that is commonly wavy and irregular.

Such highly metamorphosed rocks are termed "phyllites," or "mica schists."

One of the most abundant minerals in mica slate is white mica, which, being secondary in character, is termed "sericite." Sericite is a hydrous silicate of potash and aluminium. It is present in very minute flakes, their outlines being recognizable only under a microscope with high magnification. Small grains of quartz are also abundant, and are regularly distributed among the mica flakes. The mica-like mineral chlorite is usually present in considerable amount. Chlorites are of various kinds, the more common being hydrous silicates of aluminium and iron magnesium. Clay or kaolin is usually present in small amounts in mica slates, and may be quite abundant in clay slates. Minerals of minor importance are rutile, haematite, pyrite, carbonaceous matter, graphite, felspar, zircon, tourmaline, calcite, dolomite, siderite; very small quantities of many other minerals are commonly identified.

The chemical composition of slate varies considerably, but the following figures by Dale (*U.S.A. Geol. Survey Bull.*, 586, 1914) may be taken as average figures for the chief constituents.

Silica	55-67	Soda	0.50-3.97
Alumina	11-23	Magnesia	0.88-4.57
Ferric Oxide	0.52-7	Lime	0.33-5.20
Ferrous Oxide	0.46-9	Water above 110° C.	2.82-4.09
Potash	1.76-5.27		

An average specimen of slate may be presumed to possess physical and electrical properties in accordance with those shown in Table XXV, which sets forth the corresponding properties for slate and other switchboard materials. One of the chief troubles encountered in slate for electrical work is the presence of "metallic veins," due to the presence of pyrites, magnetite, and similar mineral matter. It is extremely difficult to determine the extent to which such impurities are present without adopting an elaborate method of high tension testing and X-ray examination. Many firms, therefore, regard all slate as under suspicion, and insulate with mica or micanite bushes and washers, every piece of apparatus mounted upon it.

The porosity value for slate, as determined by the E.R.A. method of test, is shown in Table XXV. It may be pointed

out that this figure applies to a fair quality "mica slate." In general, mica slates, as used in the electrical industry, are not extremely hygroscopic, and if a specimen is left half submerged in water for as much as 24 hours the moisture will not rise perceptibly above the water line, although, in the case of a clay slate, the moisture may rise as much as 2 in. in an hour, on account of the capillarity of the porous clay. For this reason, "clay slates" are not to be recommended for electrical purposes without special treatment. Singularly little information is available in general with regard to slate for electrical work, although the British Engineering Standards Association has issued a Specification (No. 160, 1923) on "Slate Slabs for Electrical Purposes." This specification does not give any great detail of the technical properties required in a good slate, beyond stating that it should withstand a temperature of 121°C . for 12 hours without cracking.

The following specification has been officially recognized in the U.S.A., and may serve as a general guide; it also contains some interesting data as to the methods of supporting slate panels to minimize risk of fracture on switchboards.

1. Natural slate to be used for electrical purposes shall be of clear mill stock, of uniform colour, and free from veins, spots, and cracks.

2. The slate shall be of uniform dense texture and have a specific gravity of about 2.8.

3. The porosity or factor of absorption shall not be in excess of 0.3 per cent.¹ The tensile strength shall be about 3,500 lb. per sq. in.; compressive strength not less than 10,000 lb. per sq. in.

4. The modulus of rupture shall not be less than 8,000 lb. per sq. in., the modulus of elasticity should show about 8,000,000 lb. per sq. in.

5. The slate shall be relatively soft and easy to drill; hardness, as tested on a Dorry machine, should show about 4 per cent wear, or, if abrasion is determined relative to the French coefficient, it should show about 10 per cent.

6. The slate shall be rather tough; when tested on a Riehle impact machine to determine toughness, that is, resistance to fracture under impact under the method as advocated by the American Society for Testing Materials, it shall show not less than a factor of 12.

7. The coefficient of expansion shall be less than 0.00002.

8. The slate shall be able to withstand a temperature of 200°C . without showing cracks, such temperature as in actual practice might be caused by a circuit breaker or switch stud carrying an overload of current. The slate shall also not crack if any heat-radiating resistance unit was mounted within 3 in. of the surface of the slate, provided that

¹ Porosity factor here referred to is determined by American Bureau of Standards Method.

such radiation of heat would not cause on the surface of the slate a temperature in excess of 175° C.

9. The ohmic resistance of 1 cu. in. of slate shall not be less than 400,000 ohms; also the resistance measured lateral to the cleavage of the slate by means of clamping metallic studs through the slate, the nearest metallic parts to be 1 in. apart at the surface, should show not less than 300,000 ohms.

10. The slate shall not be used for electrical purposes until after three months from the date of quarrying the same.

11. The face and edges of panels shall have even, true surfaces, accurately cut to dimensions given, and shall not vary more than one-sixteenth of an inch. Any adjoining edges or sides shall not deviate from a right angle by more than one thirty-second of an inch per linear foot. Bevels shall be cut true entirely round panels and shall be measured by the projected width and depth. Backs of panels shall be free of lumps or depressions.

12. Finish upon all edges, bevels, and exposed faces shall be honed finish, true to a line. Backs shall have sand rubbed finish, but need not be trued.

13. Holes drilled in the slate for the purpose of securing it to the supporting angle-iron or pipe framework, shall be from 15 to 20 per cent larger in diameter than the screws, bolts, cap screws, or studs used for this purpose; also between the surface of the slate and the points of contact on the supporting framework, there shall be interposed compressible washers of suitable size of such material as rubber, leather, felt, etc., to compensate for the irregularities of the surface of the framework.

14. Slate slabs over 4 ft. sq. in area, mounted on framework, shall rest on an angle-iron support so that, whenever possible, the fastening bolts, screws, or studs do not carry the weight of the slate, but only hold the same in place. In case of large switchboard assemblies, all panels shall rest on a substantial channel iron base, preferably cushioned with a strip of the above-mentioned compressible materials between the slate and the base.

2. Marble.

In its geologic sense, the term marble is applied to rocks consisting of crystallized grains of calcite or dolomite, or a mixture of the two. Although limestone has the same chemical composition as marble, it differs from the latter in that the component particles of calcium or magnesium are granular and non-crystalline.

In marble, the crystals may be intimate, whereas limestone is an aggregation of unrelated particles cemented together into a solid mass. Commercially, however, the word marble is much more widely applied, and is used to describe a wide range of calcareous rocks which are capable of taking a polish.

Certain limestones which show a fine granular structure are sold as marbles. Serpentine rocks, even when containing little calcium or magnesium carbonate, are also referred to as marbles, although correctly they should be regarded only as substitutes for true marbles.

True calcite marble may contain from 96 to 99 per cent calcium carbonate. Dolomite marble, on the other hand, contains approximately 54 per cent calcium carbonate and 46 per cent magnesium carbonate. Marbles consisting of mixtures of calcite and dolomite may have a composition anywhere between these two.

Chemical impurities which are met with in these marbles include silica (SiO_2), iron oxides (Fe_3O_4 , Fe_2O_3), magnesium oxide (MgO), alumina (Al_2O_3), and sulphur. Other metallic oxides and not infrequently organic impurities also occur.

The impurities in marble are generally in the form of small grains of mineral too minute to be visible without the use of a lens. In certain instances, however, these mineral impurities attain a considerable size. The more common mineral impurities are quartz, haemitite, limonite, graphite, mica, chlorite, tremolite, hornblende, pyrites, tourmaline.

The crystalline grains of calcite and dolomite that make up a marble mass have a definite rhombohedral cleavage and are for the most part twinned. Both the cleavage and the twinning of each grain are independent of the other grains. The texture is, therefore, usually about the same in all directions, although in some marbles elongation of the grains in one direction has been noted. The presence of such elongated grains gives certain marbles a property known to the quarrymen as the "rift," and determine the direction in which the marble should be split and sawn. The degree of interlocking of grains and direction of rift also have definite relation to the mechanical and physical properties of the material.

Marbles are commercially defined as fine, medium, and coarse. An effort has been made by various customers to get a more scientific definition of texture than that employed by these terms, and it can be generally assumed that extra fine and fine marbles are those in which the grain diameter does not exceed 4.7 mils. In medium grained marbles, the

grain diameter should not exceed 5.9 mils; coarse grained marbles may be taken as those in which the grain diameter exceeds 9.4 mils. For electrical purposes, the porosity of marble is of importance, as it directly affects its moisture absorption properties, and therefore porosity is commonly expressed as ratio of absorption, which is the percentage of weight the absorbed water bears to the absolutely dry weight of the specimen of marble under test. The method of making this test is referred to in Appendix I, and the absorption figure for a good quality marble should not exceed 0.26 per cent.

Some information with regard to the general properties of marble is given in Table XXV on page 216.

Substitutes for Slate and Marble.

Many substitutes for slate and marble are available and are used to a limited extent. Substitutes for slate are for the most part materials of the kind classed by the E.R.A. as "Class D, Self-extinguishing Boards," and consist of "asbestos slates," containing bitumen in some form to render them moisture resisting, and permit a high polish to be given to them.

Ebony asbestos wood, ebony syndanyo, siluminite, and transit asbestos wood may be mentioned as typical materials of this kind.

Artificial marbles are generally oxychloride cements (all Chap. XXI) to which pulverized marble has been added as a filler. These materials can be made closely to resemble genuine marble by the addition of suitably distributed coloured fillers. The characteristic properties of artificial marbles are similar to those of materials shown in Table XXV.

List of Products and Trade Names of Materials Dealt with as Substitutes for Slate and Marble.

RHADOONIT. A specially produced substitute for slate and marble developed by Rhadoonit-Werke Kurt Wurzner, of Weesenstein bei Dresden, in 1910, and used extensively in Germany.

SYNDANYO (*Ebony Grade*). An E.R.A. Class D non-ignitable board, sold by Asbestos & Electric Fittings Co., Ltd., of London.

TRANSIT ASBESTOS WOOD. An E.R.A. Class D non-ignitable board, produced by the Johns-Manville Co., of U.S.A.

SILUMINITE. (See Appendix to Chapter XVII.)

CALBONITE. An imitation marble supplied by Bells United Asbestos Co., of London.

MAREZZO MARBLE, SCAGLIOLA, AND MOREAU MARBLE. These are representative of a number of artificial marbles produced with oxy-chloride cements, etc., which are chiefly used for building and decorative work, but which may be employed for certain electrical purposes.

PIXTONET. A substitute for slate, suitable for high-voltage switch-board panels, supplied by Kynaz Products Co. of Ceinws, N. Wales.

CHAPTER XX

STEATITE, SOAPSTONE, ETC.

THE mineral Steatite is the base of a number of electrical insulating products capable of withstanding excessively high temperatures.

Steatite (German *Speckstein*) is rock talc or magnesium silicate, with the chemical formula $\text{H}_2\text{O} \cdot 3\text{MgO} \cdot 4\text{SiO}_2$ and occurs in nature as a creamy white (sometimes greyish or greenish) mineral which has a characteristic greasy or soapy feel. It is soft and can readily be cut with a knife. Soapstone and potstone are less pure forms of steatite.

In the manufacture of high temperature resisting insulators, the rock is machined to dimension in its natural relatively soft state and is then subjected to a baking for a period of several hours at approximately $1,100^\circ\text{C}$. This cements the material into an extremely hard product, which is available on the market under various trade names. (See Appendix to this chapter.)

Materials made in this manner from good steatite rock may be expected to possess an electric strength at 20°C . of 90 to 250 volts per mil (varying with thickness), and have a specific gravity of 2.5 to 2.7. These materials resist compression stresses well and have an ultimate compression strength of 20,000 to 25,000 lb. per sq. in.

Another steatite product is made from the turnings and fragments in working up the natural rock. This product is made by crushing and grinding the natural product, mixing with a binder, and then working up into a homogeneous mass, which is extruded under hydraulic pressure to form rods and special sections. The material produced in this way is subsequently machined to shape and baked in the same manner as steatite articles produced from the solid raw material described above. The properties of these so-called steatite composition products are slightly inferior to those of the solid baked steatite—porosity in particular being much higher than

in the composition product. Composition lava, produced by the American Lava Co., of Chattanooga, Tennessee, U.S.A., is a product of this kind. (Fig. 41.) Considerable quantities of this material are used for winding bare wire resistances, and for scientific instrument work. Steatite and soapstone are also used in admixture with clays and felspar in the production of special low porosity porcelains. Melalith, produced by the Steatit-Magnesiawerke (Steamag), of Nurnberg, is an example of such a material which, according to Bultemann, has a contraction during the firing process of 6 to 9 per cent, as against 15 to 18 per cent for porcelain and only 1 per cent for steatite itself. For accurate parts, such as are used in instrument and scientific apparatus work, this low contraction after accurate machining renders steatite a most useful insulating and high temperature resisting material. Materials such as Melalith also have their useful sphere where contraction during firing is required to be less than that characteristic of porcelain.

List of Products and Trade Names of Materials Dealt with as Soapstone, Lava, Etc.

BAKED STEATITE. This is a heat-treated steatite supplied by Wm. Sugg & Co., Ltd., of Ranelagh Works, Chapter Street, Westminster.

COMPOSITION LAVA. This is virtually a moulded composition made from steatite scrap powdered and repressed into moulded parts by the American Lava Corporation.

LAVA. This is a heat-treated steatite produced by the American Lava Corporation of Chattanooga, Tenn., U.S.A.

LAVAROCK. This is a heat-treated steatite produced by M. Kircherberger & Co., Inc., of 1425 Thirty-seventh Street, Brooklyn, New York.

LAVITE. A baked steatite product produced by the D.M. Steward Manufacturing Co., of Chattanooga, Tenn., U.S.A.

MELALITH. A steatite-porcelain product having characteristics between those of steatite and porcelain, and produced by "Steatit Magnesiawerke of Nurnberg."

PIERITE AND ROCATINE. Two materials of the type dealt with in Chapter XX, produced by Presspahn and Electrical Insulating Material Manufacturing Co. (formerly H. Weidmann), of Rapperswil.

STEATITE. A natural mineral. (See text of Chapter XX.)

CHAPTER XXI

INSULATING CEMENTS AND ADHESIVES

THE cements and adhesives used in conjunction with insulating materials are frequently the cause of more trouble in the operation of electrical plant than the insulating materials themselves. This is possibly due to the relatively small consideration which is given to the selection and use of these important subsidiary materials. In the following paragraphs a few brief notes are set down dealing with (1) cements for porcelains, etc.; (2) commutator cements; (3) adhesives for use in winding electric machinery, as "tape stickers," etc. The use of shellac varnish, synthetic resin varnishes, and similar products as cements for building up varnish paper products, mica products, etc., has been dealt with in earlier chapters. The cemented asbestos products have also been separately dealt with in Chapter XVII.

1. Cements for Porcelains.

For the cementing together of composite porcelain insulators and for securing metal supporting parts to porcelain, a number of cements are employed—

OXYCHLORIDE CEMENTS. These cements are mixtures of either zinc oxide and zinc chloride or magnesium oxide and magnesium chloride. Although the oxides and the chlorides can be mixed without a filler, such cements have a very considerable expansion on setting, and for this reason a filler is generally employed. Asbestos powder, marble dust, powdered glass, etc., are frequently used, the proportion being in the order of magnesium oxide (MgO), prepared by calcining magnesite (MgCO_3), 7 parts; magnesium chloride (MgCl_2) specific gravity 1.16 to 1.26, 6 parts; pulverized filler, 6 parts. Cements of this kind made from magnesia compounds are frequently referred to as "Sorel Cements" or "Magnesia Cements." Similar cements made with zinc oxide and zinc chloride are on the market under various trade names.

KEENES CEMENTS. The name "Keenes Cement" covers a variety of plaster of Paris cements made by calcining plaster of Paris and immersing in a solution of alum or aluminium sulphate, after which the cement is dried and calcined at a red heat. The cement is mixed with water for application, and is successfully used for cementing bushings of all kinds into metal work where not likely to come into contact with hot oil. Macks cement, Martins cement, and Parian cement are all more or less varieties of Keenes cement, using solutions of potassium or sodium sulphate, potassium carbonate, and borax respectively, instead of alum. Alabastrine is another cement of this nature.

PORTLAND CEMENT. Portland cement is a product made by heating an intimate mixture of calcareous and argillaceous materials to incipient fusion and grinding the resultant clinker to a fine powder. Many different materials are employed, but are mixed in such a way as to produce a mixture of approximately 25 per cent aluminium silicates (and free silica), and 75 per cent calcium carbonate. The manufacture of this material is carried out on an enormous scale in all parts of the world for structural and engineering work, but the cement is also very successfully employed for cementing porcelain parts, etc., particularly as it is quite unaffected by dampness, and, in fact, sets better in steam than in air. For this reason, when used for cementing parts unaffected by moisture, the cement is frequently exposed to steam or water whilst setting. Portland cement takes 4 to 10 days to set. Many forms of Portland cement are on the market, including so-called white Portland cement, which is free from iron compounds and is white in colour, thus lending itself to use for cementing together white porcelains. Some electrical manufacturers mix Portland cement with hot glue, shellac varnish, and similar products for fixing metal parts into porcelain insulators.

LITHARGE AND GLYCERINE. A cement made from approximately 3 lb. of dry litharge mixed with 1 lb. of glycerine is found suitable for cementing porcelain into iron work. This cement was used for many years by various manufacturers for sealing the corrugated sheet-iron sides of transformer tanks into cast-iron bases, since it has the property of being oil

resisting. The cement should always be used as thick as it can be manipulated, because the presence of glycerine in excess diminishes its strength. It requires from 8 to 12 hours to set, although parts into which it is run can safely be handled after 2 or 3 hours.

SULPHUR CEMENTS. Sulphur by itself affords a quite efficient cement for many purposes, although it has a tendency to be brittle. More generally the sulphur is mixed with silica or pulverized glass. This cement has the disadvantage that it requires to be run in hot—a temperature of approximately 125 to 140° C. being usual. The parts cemented together have also to be brought up to a correspondingly high temperature before pouring, which constitutes an additional difficulty in many cases. This cement has the advantage of setting quickly. Sulphur is also used in conjunction with certain bitumens and pitches in making insulating cements.

ISOLOSE (*Synthetic Compounds*). A completely different group of cements is represented by a material sold under the name Isolose by the La Porcelaine Haute Tension of Paris. This cement is supplied in the form of a liquid which is introduced with a suitable catalyst into the joint to be made. A chemical reaction ensues, resulting in the formation of a hard compound which it is claimed constitutes an excellent cement. The exact natures of the liquids employed are not available.

BABBITS, LEAD, ETC. Babbitts and other soft metals are quite frequently used for securing metal pins, studs, etc., in porcelain parts, and apparently with excellent results, since many of the largest firms in the United States adopt this method. Such materials cannot, however, be regarded as insulating cements and hardly find a place in this work.

CEMENT FOR REPAIRING PORCELAIN. For the repairing of chipped porcelain (where such a practice is allowable), magnesium oxychloride cements may be used, utilizing white sand as a filler.

2. Commutator Cements, Fillings, etc.

Commutator cements are employed for filling the space between commutator bars in commutators (particularly of

large size) where the mica has been deeply undercut. For this service the cement must obviously be a good insulator and one which does not tend to pulverize or break away when subjected to frequent temperature changes and heavy mechanical stresses due to centrifugal force, etc.

A number of satisfactory cements are on the market for this purpose, but for the most part they consist of plaster of Paris and Dextrine (in the proportions of approximately 9 to 1), mixed with water. Such cements, since they are fundamentally composed of plaster of Paris, must be mixed immediately before using. Commutator cements require approximately two days to set before the commutator may be cleaned down.

For filling other interstices which occur in electrical machine insulation, bituminous and sometimes thick shellac varnishes are quite regularly used as fillers. This question has, however, been fully considered in Chapter XI.

3. Adhesives for Fastening off Tapes, etc.

Many otherwise excellently insulated machines have failed on service owing to the use of unsuitable materials for fastening off taping on insulating windings. A great number of special insulating glues are on the market for this purpose. Many of these constitute refined animal glues free from acid or preserving matter likely to injure the insulation. Adhesives made from stearine pitch and other carefully refined products of the bitumen series are also used, whilst shellac varnish can, of course, always be relied upon as a safe product to use in case of necessity. All of these materials should only be used where they are going to be protected with some further insulation. When completing taped bars, etc., it is not satisfactory to leave the tape end secured with an adhesive of the above-mentioned kind only. Stringing, stitching, or tying off with fine string should be resorted to.

List of Products and Trade Names of Materials Dealt with as Insulating Cements.

ALABASTRINE. A special water mixing cement supplied by La Porcelaine Haute Tension, of Paris.

BASOLIT. A cement for porcelain made by W. Biesterfeld & Co., G.m.b.H. of Hanover.

HEIDELBERG RAPID. A special porcelain cement made by Heidelberger Gipsindustrie, G.m.b.H. Heidelberg.

ISOLIT. A cement supplied by D. M. Henderson & Co., Ltd., for fastening porcelain insulators, etc., to metal supports and for similar work. Claimed to set in 15 min. and be free from expansion or contraction troubles.

ISOLOSE. A cement supplied by La Porcelaine Haute Tension, of Paris, for cementing porcelain into ironwork. Cannot be used for cementing metal studs, etc., into porcelain.

MAGNESIUM OXYCHLORIDE CEMENT. (See description in text of Chapter XXI.)

PORTLAND CEMENT. (See description in text of Chapter XXI.)

COLD-JOINTINE, COLD WELDIT, ROSA-KITT, AND MASTIC 66s. These are all special cements for porcelains and similar work produced by Postler, of Niedersedlitz, Dresden.

CHAPTER XXII

OXIDE FILMS AS INSULATORS

THE oxides of many metals are found to behave as insulators, even although the metals themselves may be excellent conductors.

This fact has been made use of in numerous applications from time to time, and probably the most important of these is the employment of bare aluminium wire for field coil windings, etc., in which case the natural oxide on the metal is frequently relied upon to give sufficient insulation. The more extensive use of this material is not debarred by any technical objection from the insulation point of view, but by the difficulties of jointing aluminium conductors and by the exorbitant cost of the metal itself.

When higher insulating values are required, however, and also for producing the insulating film on the so-called aluminium oxide-film lightning arrester, the film has to be produced by an electro-chemical process, using an electrolyte of silicate of soda solution.

The oxides of copper and iron are also good insulators, but although many attempts have been made to utilize this characteristic, they have so far not resulted in any extensive commercial application. Oxide of iron is, however, frequently relied upon to give the necessary insulation between core plates in the construction of certain classes of electrical machinery.

APPENDIX I

IN the introductory chapter some reference has been made to the impossibility of comparing test results on insulating materials made by various authorities, due to the complete absence until recently of any standardized methods of making even the simplest tests. In the following pages a general *résumé* is included of such standard methods of test as have already been definitely adopted by the recognized authorities in Great Britain—i.e. the British Engineering Standards Association and the British Electrical and Allied Industries Research Association. As yet these test methods have only been definitely applied by the above-mentioned authorities to specific materials, so that in the introductory paragraphs to the various tests described the letters (B.E.S.A.) or (E.R.A.) following the name of any particular material indicate that the method in question has been definitely applied to that material by the association named. Where no qualification of this sort follows the name of the material, the application of the test to that particular material represents the author's own suggestion.

"Conditioning" plays a very important rôle in determining what characteristics any given tests will show a material to possess, so that in every test method cited the exact "condition" of the material has been closely laid down.

The absolute imperativeness of adhering to these conditioning clauses cannot be too highly emphasized if test results of any value for comparative purposes are required.

Generally speaking, the E.R.A. has recognized the seven standard "conditions" indicated in Appendix II.

In order to avoid unnecessary test work when new materials are being purchased, it is essential that a very definite line be drawn between the essential tests for safeguarding purchases of insulating materials, and what may be called Research tests for acquiring technical data for the guidance and information of designers and draughtsmen. Table XXVI is intended as a guide to indicate what tests may be applied as Research tests (denoted by letter R.) and what tests should be sufficient for ordinary purchasing requirements (denoted by the letter A = abridged).

TEST No. 1

MEASUREMENT OF THICKNESS

A. Applicable to—

Vulcanized fibre (E.R.A.), pressboards (E.R.A.).

Varnish paper and varnish fabric products (E.R.A.) and non-ignitable boards and mouldings (E.R.A.).

Also applicable to timbers, mica products, slates, hard rubber products, and similar materials when supplied in the form of boards, tubes, or rods.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before measurements are made. In the case of hard rubber (ebonite, etc.) and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish-paper products made with natural resin and gum bonds (E.R.A. Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing bitumen and rubber shall be regarded in the same category as hard rubber (ebonite, etc.) and Class D non-ignitable boards and mouldings.

METHODS OF MEASUREMENT

Boards. Measurements shall be made by means of a suitable micrometer at ten points equally spaced round the sides of the board. The maximum, minimum, and mean values of the thickness shall be stated.

Tubes. The internal and external diameters of tubes shall be measured at each end, two measurements being made on diameters at right angles to each other in each case. The measurements shall be made by means of a suitable micrometer. The maximum, minimum, and mean diameters shall be stated.

Rods. The diameters of rods shall be determined in the same manner as that indicated above for the external diameters of tubes.

B. Applicable to—

Untreated and treated papers (E.R.A.) and untreated and treated fabrics (E.R.A.).

Also to untreated and treated tapes.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *normal* conditioning before measurements are made. The material shall be tested as soon as possible after removal from the controlled atmosphere and in any case before three minutes have elapsed.

METHODS OF MEASUREMENT

Sheets. In the case of sheets, ten measurements of thickness equally spaced across the sheet shall be made. The maximum, minimum, and mean values of the thickness shall be stated.

Rolls. In the case of rolls, a test piece 1 ft. long, and the full width of the roll shall be taken sufficiently far from the end to represent the bulk of the material. Ten measurements of the thickness equally spaced diagonally across the test piece shall be made.

Tapes. In determining the thickness of paper and fabric tapes, it is suggested that ten measurements be taken equally spaced along a yard length, cut sufficiently far from the end of the roll to represent the bulk of the material. When the tape is wider than the diameter of the micrometer face, care should be taken to ascertain that measurements are made staggered across the width of the tape and, in the case of fabric tapes, including both selvages.

Micrometers. The E.R.A. directions specify that thickness measurements shall be made with a "suitable micrometer." Much latitude is therefore allowed in the selection of this important piece of apparatus. For hard dielectrics, boards, etc., an ordinary micrometer with a face not more than approximately $\frac{1}{4}$ in. diameter can be regarded as "suitable," but for soft materials, such as papers, fabrics, etc., a paper-measuring micrometer with $\frac{3}{8}$ in. to $\frac{7}{16}$ in. diameter faces, one of which is "swivel-mounted," is to be recommended.

A ratchet head is generally to be recommended for all measurements on insulating materials, and a good rule is to read the micrometer after the ratchet has "clicked" over five notches slowly. Even with a ratchet head, however, the accuracy of the reading is largely a question of touch and experience of the operator, and a skilled man will be able to use a simple micrometer without a ratchet with even greater accuracy than a less skilled man with a ratchet attachment.

For refined measurements on resilient materials, a piece of apparatus, such as the Piezo micrometer, introduced recently by Mr. Straughan, of Aberdeen, gives results which are beyond question, as it allows a curve to be plotted of the micrometer readings corresponding to various pressures of the micrometer faces

In measuring the thickness of fabrics and papers of all classes, more reliable average results can generally be obtained by measuring, say, ten thicknesses together.

TEST No. 2

DETERMINATION OF DENSITY

A. Applicable to—

Vulcanized fibre (E.R.A.), varnish paper and varnish fabric products (E.R.A.), and non-ignitable boards and mouldings (E.R.A.).

Also applicable to slates, hard rubber products, moulded compositions, and similar materials when supplied in the form of boards, tubes, or rods.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the determination of density is made. In the case of hard rubber (ebonite, etc.) and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing bitumen and rubber shall be regarded in the same category as hard rubber (ebonite, etc.) and Class D, non-ignitable boards.

METHODS EMPLOYED

(a) *Boards.* A specimen $1\frac{1}{2}$ in. square and of thickness equal to the thickness of the material shall be employed.

The area of the specimen shall be computed from the mean of ten measurements of the length and the width respectively at points equally spaced along each of two edges at right angles.

The thickness shall be determined by making ten measurements with a suitable micrometer equally spaced around the sides of the board, and the mean value shall be taken in computing the volume of the specimen.

The usual precautions shall be taken in weighing the specimen, and the weight shall be taken to the nearest milligramme in each case.

The density shall be expressed in terms of weight in grammes per cubic centimetre.

Note. When carrying out acceptance tests on bulk consignments, it will frequently be found desirable to weigh and measure the entire boards as received. This test affords a rapid means of checking the density of the material without cutting the board, and should be conducted before cutting specimens for other tests.

METHODS EMPLOYED

(b) *Rods and Tubes.* The dimensions of a rod or tube $1\frac{1}{2}$ in. long shall be determined by means of a micrometer or other suitable method.

The diameter of the rod, and in the case of a tube the internal and external diameters of the tube, shall be measured at each end and at the centre. Two measurements shall be made on diameters at right angles in each case. The length of the specimen shall be determined by making four measurements equally spaced round the circumference of the ends, and in the case of a rod a fifth measurement shall be made on the axis of the rod. The volume of the specimen shall be computed from the mean value in each case.

The usual precautions shall be observed in weighing the specimens, and the weight shall be taken to the nearest milligramme in each case.

The density shall be expressed in terms of weight in grammes per cubic centimetre.

B. Applicable to—

Pressboard (E.R.A.).

It is suggested here that this test is probably more applicable to the thinner makes of vulcanized fibre (including leatheroid, etc.), varnish paper products, thin ebonite, etc., than that described above as Test No. 2 *A*.

Also applicable to mica products and other materials when supplied in thin sheets.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the determination of density is made.

METHOD EMPLOYED

The specimen shall consist of either a disc 3 in. diameter or a square with 3-in. sides. The thickness of the specimen shall be that of the material as supplied.

The area of the specimen shall be computed, in the case of the disc, from the mean of ten measurements of the diameter at equi-distant points around half the circumference, and in the case of the square from the mean of ten measurements of the length and the width respectively at points equally spaced along each of two edges at right angles. The thickness shall be determined by making ten measurements with a suitable micrometer equally spaced around the circumference in the case of the disc, and around the sides in the case of the square, and the mean value shall be taken in computing the volume of the specimen.

The usual precautions shall be taken in weighing the specimen, and the weight shall be taken to the nearest milligramme.

The density shall be expressed in terms of weight in grammes per cubic centimetre.

(C) Applicable to—

Untreated and treated fabrics (E.R.A.), untreated and treated papers (E.R.A.).

CONDITIONING

Unless otherwise specified, the material shall be subjected to *normal* conditioning before the determination of density is made.

METHOD EMPLOYED

The density shall be determined by weighing as large a sample of the material as the balance used will permit. The area of the specimen shall be computed from ten measurements of the length and width respectively.

The density shall be expressed in terms of weight in grammes per square metre.

TEST No. 3

TENSILE STRENGTH AND PLASTIC YIELD UNDER CONTINUOUS LOAD

A. Applicable to—

Vulcanized fibre (E.R.A.), pressboard (E.R.A.).

Varnish paper and varnish fabric products (E.R.A.).

Non-ignitable boards (E.R.A.).

Also applicable to hard rubber (ebonite, etc.), micanite plate, and similar products when supplied in the form of boards, rods, or tubes.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before tensile strength tests are carried out. In the case of hard rubber (ebonite, etc.) and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.) and, Class D, non-ignitable boards.

METHOD OF TEST

(a) *Boards* (E.R.A.). The form and dimensions of the specimen for testing a board shall be as shown in Fig. 42. The thickness of the test bar shall be the thickness of the material.

(i) The specimen shall be tested longitudinally and transversely to

ascertain the ultimate tensile strength and the extension of a 3-in. gauge length.

The load shall be increased steadily at such a rate that the specimen breaks in approximately two minutes from the time of the application of the load.

The ultimate tensile strength shall be expressed in lb. per square inch. The extension shall be expressed as a percentage on the original gauge length.

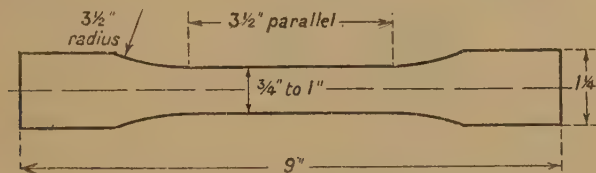


FIG. 42.—Specimen for Tensile Strength and Extension Tests in Boards.

(ii) The specimen shall be tested to ascertain the extension on a 3-in. gauge length when subjected continuously to a load of a value equal to one-third of the breaking load, determined by test (i) above. The load shall be maintained until the increase of strain ceases.

(b) *Rods* (E.R.A.). The form and dimensions of the specimen for testing a rod shall be as shown in Fig. 43.

The reduced diameter D shall be 75 per cent of the full diameter of the rod.

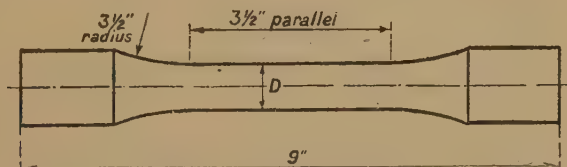


FIG. 43.—Specimen for Tensile Strength and Extension Tests on Rods.

Specimens shall be tested as specified in (a) (i) and (ii) above.

(c) *Tubes* (E.R.A.). The dimensions of the tube for test shall be 9 in. long, 1 in. internal diameter, and $1\frac{1}{2}$ in. external diameter.

Specimens shall be tested as specified in (a) (i) and (ii) above.

A suitable form of grip for holding the tube in the testing machine is shown in Fig. 44.

In the case of varnish paper and varnish fabric products, the tests shall be carried out under the following conditions—

(i) At a temperature from 15°C. to 25°C.

(ii) At the appropriate temperature given in Table I, after the specimen has been immersed in the oil specified in the following table at the high temperature for 24 hr.

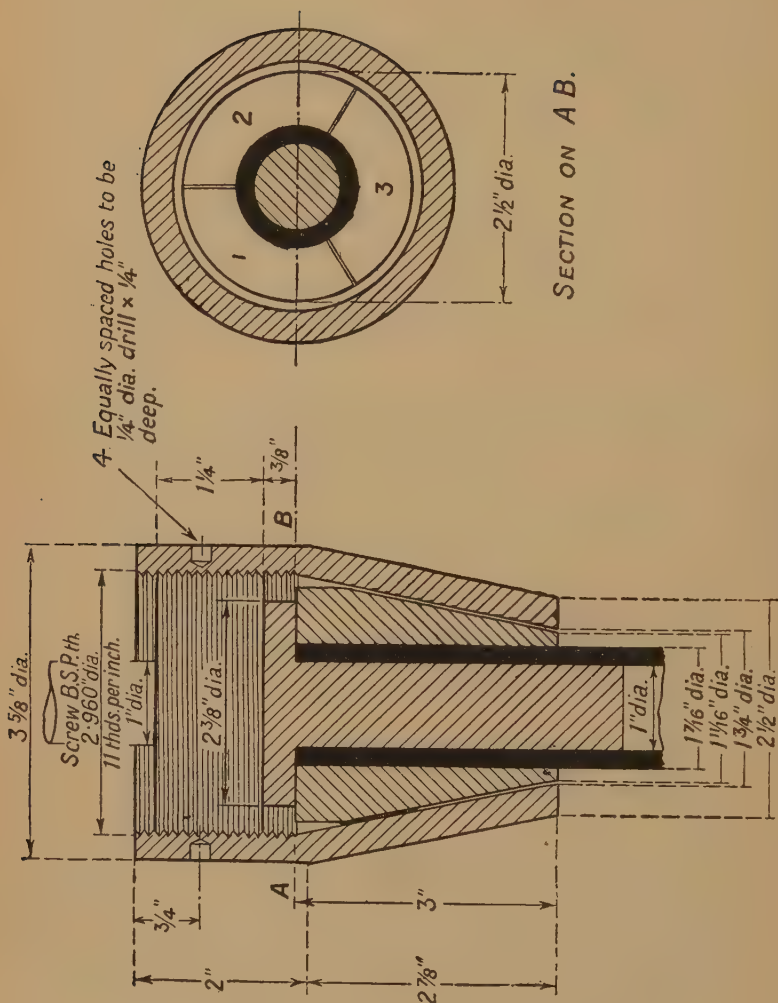


FIG. 44.—Form of Grip for Holding a Tube in Testing Machine for Tensile Strength and Extension Tests.

TEMPERATURE OF SPECIMEN IN TENSILE STRENGTH AND
EXTENSION TESTS

Material.	Limits of Temperature ° C.	Class of Oil.
Class I, Grades A and B	90-95	B.E.S.A. Specification, No. 148 for light grade oil
Class II, Grade A	90-95	
Class II, Grade B	65-70	
Class I, Grade C	145-150	Mineral oil, closed flash-point not less than 250° C.

B. Applicable to—

Unvarnished textile fabrics (E.R.A.), varnished cotton cloth (E.R.A.).

Also applicable to insulating fabrics in general.

CONDITIONING

The material shall be subjected to *normal* conditioning before the tensile strength tests are carried out. The tests shall be conducted as soon as possible after removal from the controlled atmosphere and, in any case, before three minutes have elapsed.

METHOD OF TEST (E.R.A.)

Nine specimens shall be cut in such a manner as to be representative of the bulk of the fabric. Three specimens shall be cut in the direction of the warp, three in the direction of the weft, and three on the bias at an angle of 45°. No two specimens cut in the same direction shall contain the same longitudinal threads.

The specimens shall be cut from the fabric not less than 2¼ in. wide (except in the case of the specimen cut on the bias, which shall be cut 2 in. wide) and the threads frayed out from each side to reduce the width to 2 in. The specimens shall be placed evenly in the jaws of the testing machine so that the unstretched length of the fabric between the jaws is not less than 7 in. The load shall be applied at a uniform rate, and the time taken to reach the breaking load from the commencement of the application of the load shall be (approx.) one minute. If the specimen breaks unevenly or in, or at, the jaws due to incorrect clamping, a duplicate test shall be made on another test piece, including the same threads. The maximum, minimum, and the mean values of the three tests warp way, of the three tests weft way, and of the three tests on the bias respectively shall be stated.

Normally, tests shall be carried out at 20° C., but the E.R.A. directions call for tests at 20° C., 60° C., 90° C., and 120° C. When testing at the high temperatures, the specimen shall be surrounded by a heated cylinder to maintain the required temperature.

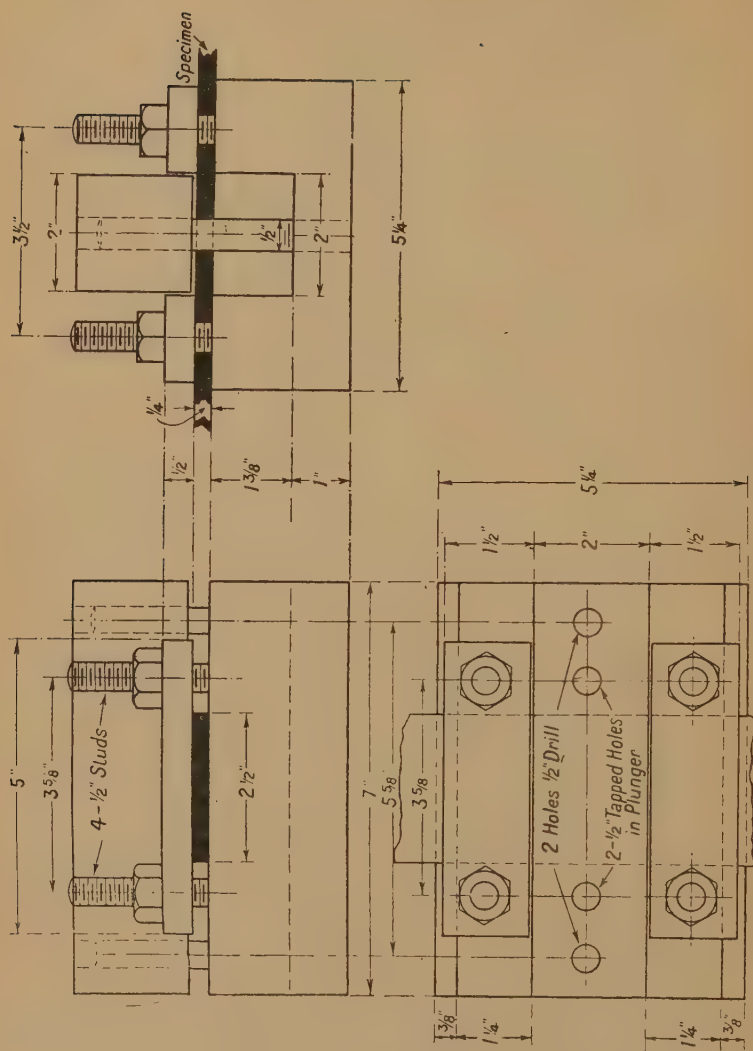


FIG. 45.—Form of Jig for Shear Test.

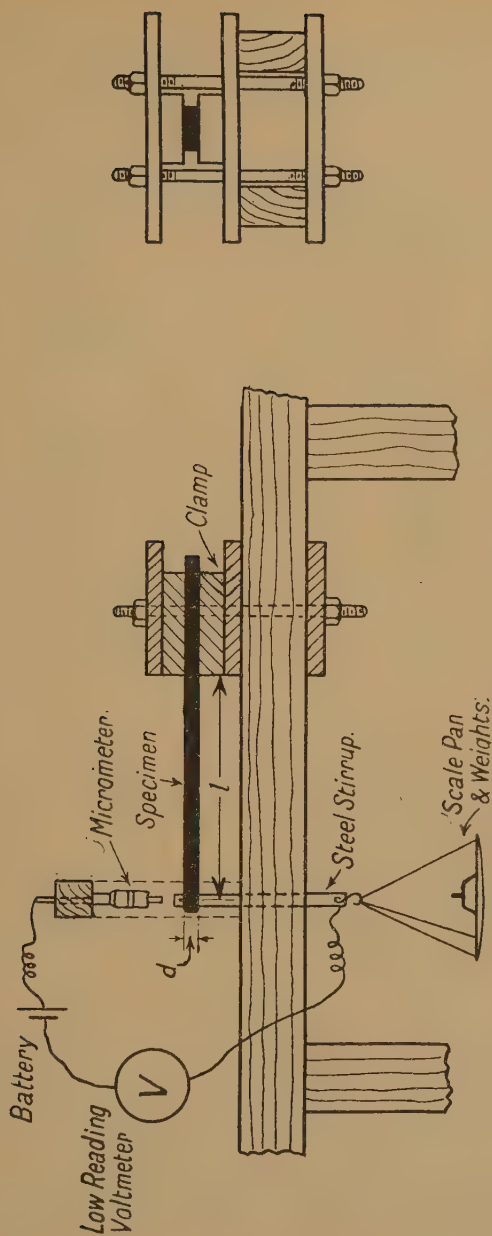


FIG. 46.—Arrangement of Cantilever Test for Boards.

No definite recommendations have been made by the E.R.A. as to the details of the apparatus to be used in carrying out tensile strength tests on fabrics. A number of suitable fabric testing machines are on the market, but if no such special machine is available, the apparatus

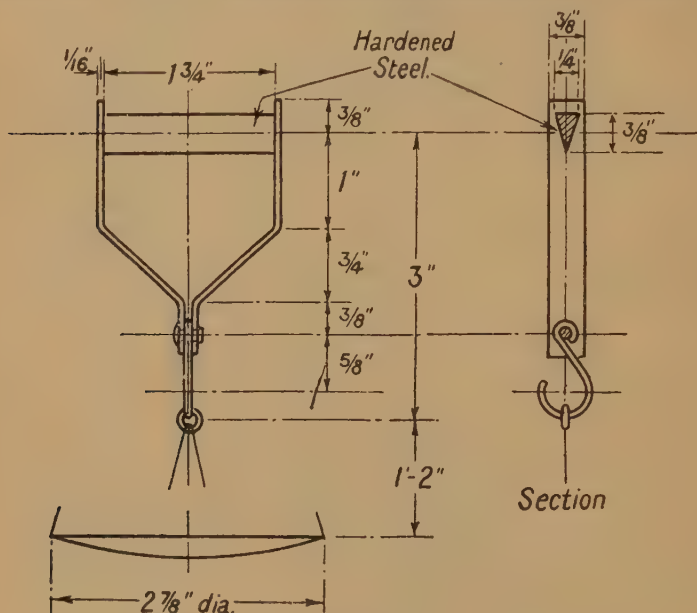


FIG. 47.—Form of Knife-edge Balance for Cantilever Test.

shown in Fig. 51 (Tearing Test No. 8) may be used. This has been found to give results sufficiently accurate for ordinary commercial tests.

C. Applicable to—

Electrical insulating papers (unvarnished) (E.R.A.).

Also applicable to insulating papers in general, including varnished papers.

CONDITIONING

The specimens shall be subjected to *normal* conditioning before the test for tensile strength is carried out. The tests shall be conducted as soon as possible after removal of the specimen from the controlled atmosphere, and in any case before three minutes have elapsed.

METHOD OF TEST (E.R.A.)

For the purpose of the test for tensile strength and extension, at least 12 test samples shall be taken. Six of these shall be cut in the direction of length of the paper and six across the width of the paper.

The dimensions of each test piece shall be $\frac{3}{8}$ -in. wide by 10 in. long, so as to give 6 in. clear between the testing jaws.

The load shall be applied gradually, and the test shall be carried out in such a manner that the tensile strength in lb. per square inch sectional area and the percentage elongation on the original length under load can be determined.

In computing the tensile strength of the paper, the mean thickness shall be determined in accordance with the directions quoted in Test No. I.B. (App. I).

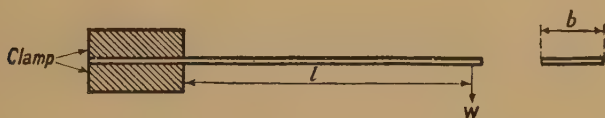


FIG. 48.—Form of Test for Stiffness or Rigidity.

The maximum, minimum, and mean values of tensile strength and of percentage extension shall be stated.

Note. Since in this case also the E.R.A. directions lay down no definite rules as to the construction of the apparatus to be employed in determining the tensile strength of papers, the apparatus referred to in (B) above, and shown in Fig. 50, may be used for commercial test work. For some of the low tensile strength (tissue) papers, this apparatus may require to be fitted with a lighter spring balance than that used for strong papers and fabrics.

TEST No. 4

COMPRESSION STRENGTH AND PLASTIC YIELD UNDER CONTINUOUS LOAD

A. Applicable to—

Vulcanized fibre (E.R.A.), varnish paper and varnish fabric products (except Class II, Grade B materials) (E.R.A.) and non-ignitable boards and mouldings (E.R.A.).

Also applicable to hard rubber (ebonite, etc.), moulded compositions, micanite plate, slates, and similar products.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the test for compression strength is carried out. In the case of hard rubber (ebonite, etc.) and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.) and, Class D, non-ignitable boards.

METHOD OF TEST

(a) *Boards* (E.R.A.). (i) The dimensions of the specimen for test shall be 1-in. cube, the specimen being built up with several layers of

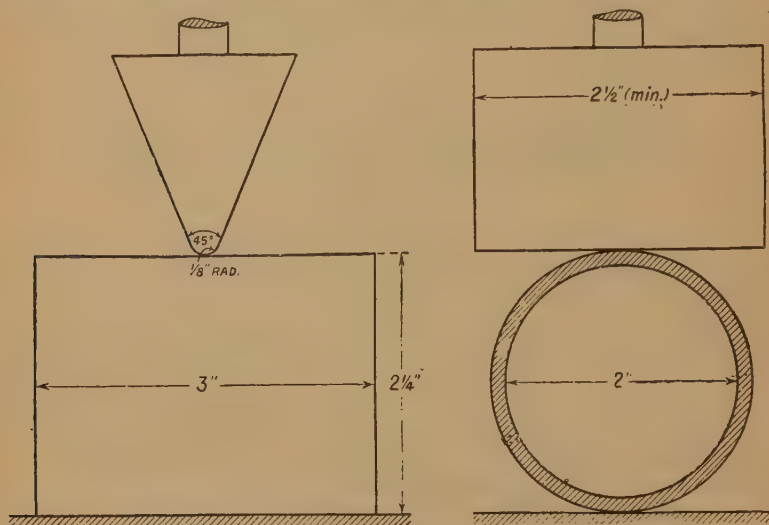


FIG. 49.—Arrangement of Stiffness Test for Tubes.

the material when necessary. The layers of the material shall be bedded together by the application of an initial load of 300 lb. per square inch, and the first measurement of the length of the specimen shall be taken under this load, which shall be included in the load registered in each case.

A series of tests shall then be carried out at a temperature from 15° C. to 25° C. by the application of increasing loads of 1,500 lb. per square inch, each of which shall be maintained for one minute, and the yield of the specimen shall be measured at the end of each period. The tests shall be continued until the specimen has yielded 10 per cent of its original length, when measured as stated above, or the load has reached about 6 tons per square inch.

(ii) A specimen similar to that described in (i) above shall be heated in air at a temperature from 90° C. to 95° C. for 24 hr., and then tested at a temperature from 90° C. to 95° C. The specimen shall be bedded, the loads applied, the yields measured, and the test continued as specified in (i) above.

(iii) A specimen similar to that described in (i) above shall be

immersed in transformer oil, complying with British Standard Specification No. 148 for light grade oil, at a temperature from 90° C. to 95° C. for 24 hr., and then tested at a temperature from 90° C. to 95° C. The specimen shall be bedded, the loads applied, the yields measured, and the test continued as specified in (i) above.

(iv) A specimen similar to that described in (i) above shall be heated in air at a temperature from 90° C. to 95° C. for 24 hr. and then subjected continuously, at a temperature from 90° C. to 95° C., to a load of a value equal to one-third of the maximum load applied in the test specified in (ii) above. The load shall be maintained until the increase of strain ceases. The yield shall be measured at intervals, and a curve plotted showing the relationship between the yield and the time of application of the load.

(v) When the thickness of the material is $\frac{3}{8}$ in. or above, it shall be also tested at a temperature from 15° C. to 25° C. for compression strength in the longitudinal direction.

The dimensions of the specimen shall be 2 in. in the longitudinal direction of the sheet and 1 in. in the transverse direction, the load being applied on the 2-in. edges of the specimen.

The load shall be increased gradually at the rate of 1,500 lb. per square inch per minute until the specimen fails. The load at which the failure occurs and the duration of the test shall be stated.

(vi) A specimen similar to that described in (v) above shall be heated in air at a temperature from 90° C. to 95° C. for 24 hr., and then tested at a temperature from 90° C. to 95° C. The load shall be applied and the test continued as specified in (v) above.

(b) *Rods* (E.R.A.). The form of the specimen for test shall be a cylinder, the length of which shall be equal to the diameter of the rod. The end faces of the specimen shall be truly plane, square, and parallel.

An initial load of 300 lb. per square inch shall be applied and the first measurement of the length of the specimen shall be taken under this load, which shall be included in the load registered in each case.

Specimens shall be tested as specified in (a) above.

(c) *Tubes*. The form of the specimen for test shall be a tube, the thickness of wall being not less than $\frac{1}{8}$ in. and the length of which shall be equal to the external diameter of the tube. The end faces of the specimen shall be truly plane, square, and parallel.

An initial load of 300 lb. per square inch, computed on the cross-sectional area of the material, shall be applied, and the first measurement of the length of the specimen shall be taken under this load, which shall be included in the load registered in each case.

Specimens shall be tested as specified in (a) above.

Note. It is not suggested that all the above tests should necessarily be carried out on one material. In the case of Class 1, Grade C varnish fabric products (i.e. those containing asbestos and non-ignitable fillers), a further test is suggested by the E.R.A. similar to (a) (iii) above, but

with the temperature raised to 145° C. to 150° C. and employing a mineral oil with a flash-point not less than 250° C.

B. Applicable to—

Pressboard (E.R.A.).

CONDITIONING

The specimens shall be subjected to *dry* conditioning before the test for compression strength is carried out.

METHOD OF TEST (E.R.A.)

The form of the specimen for test shall be either a cylinder 1 in. long and 3 in. diameter, or a prism 1 in. long and 3 in. square, the specimen being built up with sufficient layers of the material.

The compression faces of the testing machine shall be 2 in. diameter.

The specimen shall be set up for testing, so that its centre line is co-axial with the centres of the compression faces of the testing machine.

The layers of the material shall be bedded together by the application of an initial load of 100 lb. per square inch, and the first measurement of the length of the specimen shall be taken under this load, which shall be included in the load registered in each case.

A series of tests shall then be carried out by the application of increasing loads, in steps of 1,500 lb. per square inch, each of which shall be maintained for one minute; and the yield of the specimen shall be measured at the end of each period. The tests shall be continued until the specimen has yielded 25 per cent of its original length when measured as stated above, or the load has reached about 6 tons per square inch.

TEST No. 5

SHEARING STRENGTH TEST

A. Applicable to—

Vulcanized fibre (E.R.A.), pressboard (E.R.A.).

Varnish paper and varnish fabric products (E.R.A.).

Non-ignitable boards (E.R.A.).

Also applicable to hard rubber (ebonite, etc.), micanite plate, and similar products when supplied in the form of boards or thin sheets.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the test for shearing or tearing strength is carried out. In the case of hard rubber (ebonite, etc.) and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also

made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.) and, Class D, non-ignitable boards.

METHOD OF TEST

(a) *Shearing Strength.* (E.R.A.) Materials above $\frac{1}{8}$ in. (0.8 mm.) thick up to and including $\frac{1}{4}$ in. (3.2 mm.) thick shall be tested to ascertain the pressure required to punch a hole $\frac{1}{2}$ in. diameter.

The load shall be applied steadily, and shall be increased at a rate of about 100 lb. per minute for each $\frac{1}{8}$ in. thickness of the specimen.

The clearance between the punch and the die shall be negligible, as obtained by trimming the punch with the die.

The pressure required to punch the hole shall be expressed in lb. per square inch (or kg. per cm.²).

Materials above $\frac{1}{4}$ in. (3.2 mm.) thick shall be tested as follows—

A specimen, the dimensions of which shall be 5 in. long and $2\frac{1}{2}$ in. wide, shall be clamped in a shear testing machine, so that both sides of the specimen are sheared off simultaneously. The pressure required to produce shear shall be computed on the total area of the sections sheared, and shall be expressed in lb. per square inch.

A suitable form of jig for conducting this test is shown in Fig. 45.

TEST No. 6 (a)

STIFFNESS OR RIGIDITY TEST ON BOARDS

A. Applicable to—

Vulcanized fibre (E.R.A.), pressboard (E.R.A.).

Varnish paper and varnish fabric products (E.R.A.).

Non-ignitable boards and mouldings (E.R.A.).

Also applicable to micanite plate, hard rubber (ebonite, etc.), and similar products.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the test for stiffness or rigidity is carried out. In the case of hard rubber (ebonite, etc.) and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.) and Class D, non-ignitable boards.

METHOD OF TEST (E.R.A.)

Materials shall be tested for stiffness or rigidity by the cantilever method as follows—

The form and arrangement of the test shall be in accordance with Fig. 46.

The specimen shall be firmly fixed in clamps, and the knife-edge piece and scale pan (Fig. 47) placed in position as shown in Fig. 46. A measurement shall be made of the unsupported end below datum as follows—

An inside micrometer shall be clamped above the knife-edge piece. The electric circuit shall be as shown in Fig. 46. The micrometer screw shall be turned until the circuit is closed (as indicated by the voltmeter) and the micrometer reading shall then be taken.

Small equal increments of load shall be applied and the corresponding increments in deflection measured immediately.

Each increment of load shall be applied as soon as the deflection for the previous load increment has been read. Readings shall only be taken for the range during which the increment of load is proportional to the increment of deflection.

The dimensions of the test piece shall be as follows—

For specimens not exceeding $\frac{1}{16}$ in. thick :

$$\begin{aligned}\text{Cantilever length} &= 2 \text{ in.} \\ \text{Breadth} &= \frac{3}{4} \text{ in.}\end{aligned}$$

The increments of deflection shall not exceed 0.010 in.

For specimens exceeding $\frac{1}{16}$ in. thick, the cantilever length shall be from 3 in. to 9 in., according to stiffness of material.

The cantilever breadth shall be one-fifth of the length of the specimen.

The increment of deflection shall not exceed 0.015 in.

Young's Modulus E shall be calculated from the formula :

$$E = \frac{4Wl^3}{bd^3y}$$

Where

W = average increment of load, lb.

l = cantilever length, inches

b = breadth, inches

d = thickness of specimen, inches

y = average increment of deflection, inches

When the final increment of deflection has been measured as described above, the load shall not be removed. The increment of deflection shall be remeasured after one minute, 10 min., 1 hr. and 18 hr. respectively.

After the 18-hr. test has been completed, tests at loads of 0.66 and 1.5 times the value of the load employed in 18 hr. test respectively shall be applied to the specimen, and the increments of deflection shall be remeasured as before in the prolonged test.

Note. A suitable form of knife-edge balance for use in the cantilever test is shown in Fig. 47.

TEST No. 6 (b)

STIFFNESS OR RIGIDITY TEST ON TUBES

A. Applicable to—

Vulcanized Fibre (E.R.A.), varnish paper and varnish fabric products (E.R.A.).

Also applicable to hard rubber (ebonite, etc.) and similar materials.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the test for stiffness or rigidity is carried out. In the case of hard rubber (ebonite, etc.) and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

METHOD OF TEST (E.R.A.)

A tube 3 in. long, 2 in. internal diameter, and $2\frac{1}{4}$ in. external diameter shall be set up in a compression testing machine as shown in Fig. 49.

The load shall be applied to the top of the specimen and midway between the ends, by means of a wedge-shaped plunger not less than $2\frac{1}{2}$ in. wide, the bottom edge of which is rounded to a radius of $\frac{1}{8}$ in. The angle of the wedge shall be approximately 45°, and its axis shall be at right angles to the axis of the tube, as shown in Fig. 49. The load shall be increased by steps and sufficient readings of the travel of the plunger taken, up to the load at which failure occurs, to enable a stress-strain curve to be plotted.

Note. The above test, as laid down by the E.R.A., requires a special specimen to be prepared, the diameters of which are specified. This has apparently been done with the object of securing comparable results for investigational work, but the method involved and the apparatus employed can be equally well applied to any diameter of tube.

TEST No. 7

FLEXIBILITY TEST

A. Applicable to—

Pressboard (E.R.A.), vulcanized fibre (E.R.A.).

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the flexibility test is carried out.

METHODS OF TEST

(a) *In Dry Condition* (E.R.A.). *Note.* This test is applicable to all grades of pressboard from 20 mils thickness upwards, and to vulcanized fibre of all thicknesses up to $\frac{1}{8}$ in. A convenient size of specimen is one approximately 4 in. square.

Every specimen shall be bent longitudinally and transversely through a specified angle and the effect at the bend shall be stated. The diameter of the pin round which the specimen is bent shall be in accordance with the appropriate value given in the following table—

Limits of Thickness of Specimen.	PRESSBOARD. Angle of Bend, 90°. Diam. of Pin.	VULCANIZED FIBRE. Angle of Bend, 180°. Diam. of Pin.
	inch.	inch.
Above 0.020 up to and including $\frac{1}{32}$. . .	0.25	0.125
Above $\frac{1}{32}$ up to and including $\frac{1}{16}$. . .	0.375	0.25
Above $\frac{1}{16}$ up to and including $\frac{1}{8}$. . .	0.50	1.50

(b) *After Baking* (E.R.A.). The specimen shall be heated at a temperature from 105° C. to 110° C. for 48 hours, after which it shall be bent longitudinally and transversely through the specified angle, and the effect at the bend shall be stated. The diameter of the pin round which the specimen is bent shall be in accordance with the appropriate value given in the following table—

Limits of Thickness of Specimen.	PRESSBOARD. Angle of Bend, 90°. Diam. of Pin.	VULCANIZED FIBRE. Angle of Bend, 180°. Diam. of Pin.
	inch.	inch.
Up to and including 0.010 . . .	0.125	—
Above 0.010 up to and including 0.020 . . .	0.1875	—
Above 0.020 up to and including $\frac{1}{32}$. . .	0.75	0.75
Above $\frac{1}{32}$ up to and including $\frac{1}{16}$. . .	1.25	2.00
Above $\frac{1}{16}$ up to and including $\frac{1}{8}$. . .	2.00	5.00

(c) *After Heating in Oil.* The specimen shall be heated in transformer oil complying with British Standard Specification No. 148 for light grade oil, at a temperature from 115° C. to 120° C. for 48 hours, and shall then be bent longitudinally and transversely through the specified angle. The diameter of the pin round which the specimen is bent and the angle of the bend shall be in accordance with the appropriate value given in the following table—

Limits of Thickness of Specimen.	PRESSBOARD. Angle of Bend, 90°. Diam. of Pin.	VULCANIZED FIBRE. Angle of Bend, 180°. Diam. of Pin.
	inch.	inch.
Up to and including 0.010 . . .	0.50	—
Above 0.010 up to and including 0.020 . . .	1.00	—
Above 0.020 up to and including $\frac{1}{32}$. . .	1.25	1.30
Above $\frac{1}{32}$ up to and including $\frac{1}{16}$. . .	1.75	3.50
Above $\frac{1}{16}$ up to and including $\frac{1}{8}$. . .	2.00	7.25

TEST No. 8

TEARING TESTS

A. Applicable to—

Pressboarding (up to $\frac{1}{32}$ in. thickness) (E.R.A.).

Vulcanized fibre (up to $\frac{1}{32}$ in. thickness) (E.R.A.).

Electrical Insulating papers (unvarnished) (E.R.A.).

Also applicable to other insulating materials when supplied in thin sheet form.

CONDITIONING

In the case of pressboard and vulcanized fibre, the E.R.A. calls for the specimen to be subjected to *dry* conditioning before the tearing strength test is carried out. In the case of insulating papers, the specimens shall be subjected to *normal* conditioning before the test is carried out.

METHOD OF TEST

(a) *Single Tear Test* (based on E.R.A. directions). The resistance to tearing shall be proved by measuring the load required to tear the specimen commencing from a hole $\frac{3}{32}$ in. diameter punched out of it. The position of the hole and the method of applying the load shall be as shown in Fig. 50 (which also shows details of a suitable apparatus for conducting the tearing test).

The size of each specimen shall be 6 in. square.

Tests shall be made both in the longitudinal (or machine) direction and in the transverse (or "across the width") direction of the material.

The method of carrying out the test shall be as follows—

The sample shall be cut to size and secured in the jig as shown in Fig. 50. The position of the punched hole shall also be as shown—i.e. at the edge of the *L* piece. The lower free part of the specimen or tongue shall be suitably gripped with a clip or a roller grip similar to that used in roll film cameras.

The tongue shall then be drawn upwards, using a winding gear capable of producing a steady movement at a rate of approximately 12 in. per minute until a 6 in. length has been torn through. A motor drive is recommended for this purpose.

The balance shall be carefully watched during the time the pull is being applied, and the slightly varying values of the pull shall be recorded, maximum, minimum, and mean values being shown.

B. Applicable to—

Unvarnished textile fabrics (E.R.A.).

In the author's opinion the following method is also more applicable to varnished cotton cloths than the single tear method described above, which has been suggested by the E.R.A.

This method is also applicable to papers, such as tissues, etc., which are frequently difficult to test by the single tear method.

CONDITIONING

The specimens shall be subjected to *normal* conditioning before the test for tearing strength is carried out.

METHOD OF TEST

(b) *Double Tear Test* (based on E.R.A. directions). The tearing

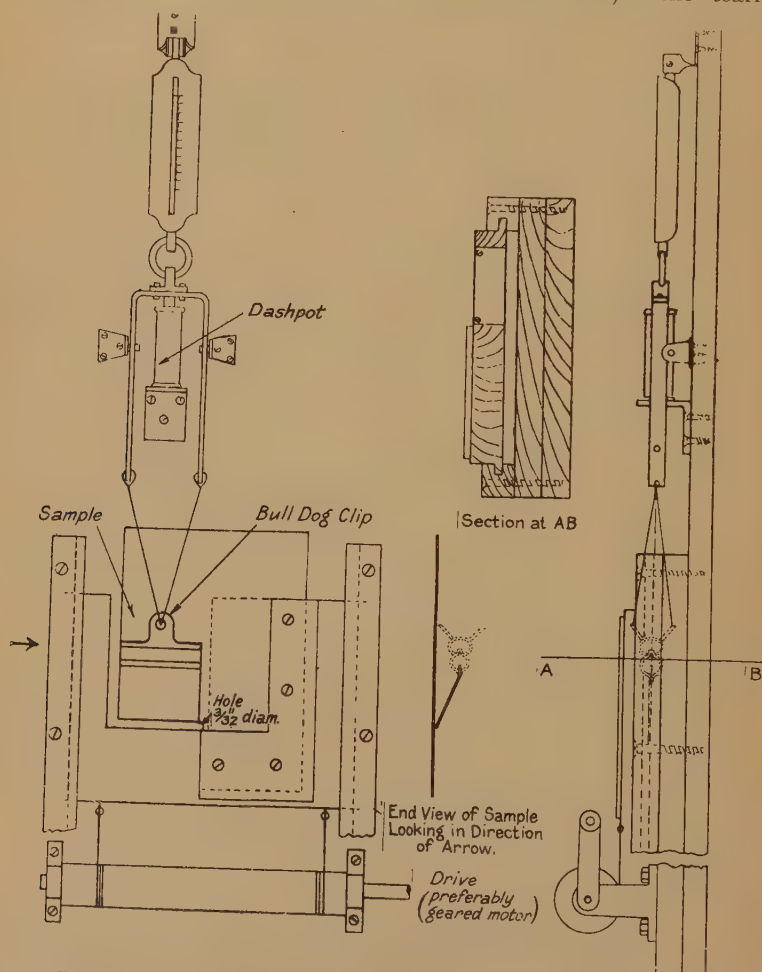


FIG. 50.—Apparatus for Measuring the Tearing Strength of Fabric (Single Tear).

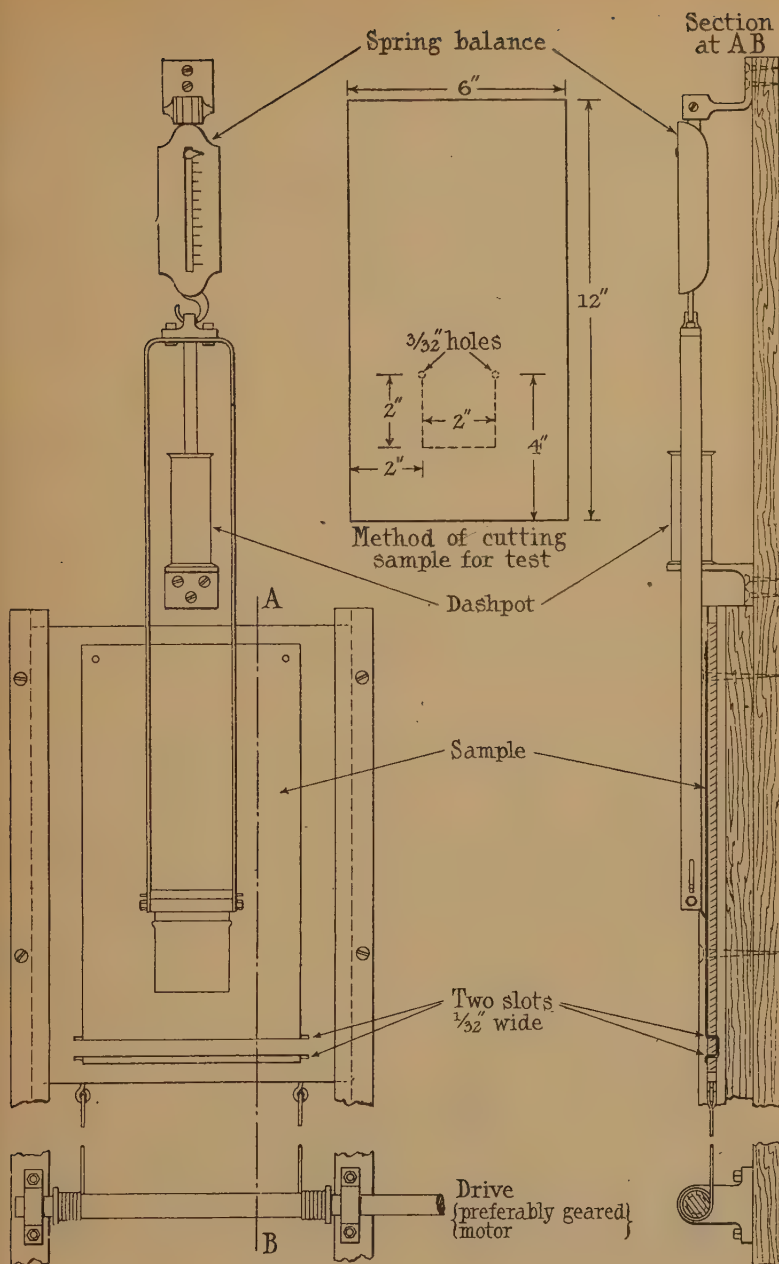


FIG. 51.—Apparatus for Measuring the Tearing Strength of Fabric (Double Tear).

test shall be carried out by means of the apparatus shown in Fig. 51, and the specimen shall be prepared and mounted as shown in the figure. The size of specimen employed shall be 12 in. by 6 in. Three specimens shall be cut from the fabric in the longitudinal or warp direction and three specimens in the transverse or weft direction.

The resistance to tearing shall be determined by measuring the load required to tear a tongue 2 in. wide, commencing from holes $\frac{3}{8}$ in. diameter punched out of the fabric.

The method of operating the apparatus and expressing the results shall be as outlined above for the single tear test.

TEST No. 9

BURSTING TEST AND EXTENSIBILITY OF FABRICS AND PAPERS

A. Applicable to—

Unvarnished textile fabrics (E.R.A.)

Varnished cotton cloth (E.R.A.).

CONDITIONING

The specimens shall be subjected to *normal* conditioning before the test for bursting strength is carried out.

METHOD OF TEST (E.R.A.)

The bursting strength shall be determined by means of the apparatus shown in Fig. 52. The method employed shall be as follows—

The fabric shall be placed over the rubber diaphragm and clamped between the rubber insertion rings fitted on top of the steel drum so as to make an airtight joint. Air shall be pumped into the drum at such a rate that the pressure on the fabric is increased gradually at the rate of approximately 30 lb. per square inch per minute until failure occurs.

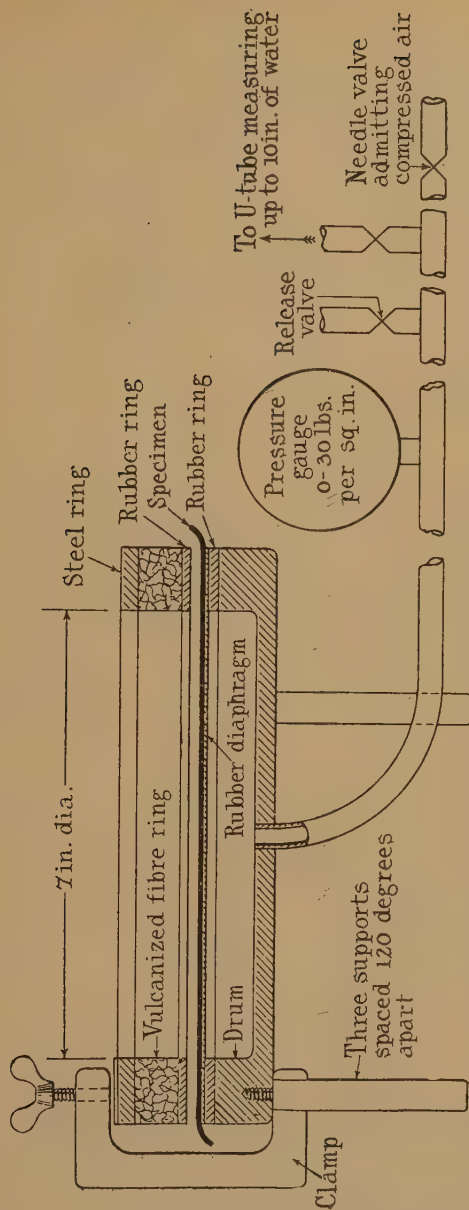
Note. Care must be taken to release the air pressure immediately the fabric fails, so as not to damage the rubber diaphragm.

The same apparatus shall be used for determining the extensibility of fabrics as used for determining the bursting strength. The method employed shall be as follows—

The fabric shall be clamped between the rubber rings as before. Air shall be pumped into the drum at such a rate that the radii of curvature of the varnished cloth diaphragm can be determined by means of a suitable spherometer. Sufficient readings shall be taken to enable a curve to be plotted showing the relationship between the air pressure and the radius of curvature of the diaphragm.

B. Applicable to—

Insulating papers, both treated and untreated,



NOTE:—The rubber ring and diaphragm are shown apart, but when in use they are brought into contact with the specimen and fixed by clamps, one of which is shown in position.

FIG. 52.—Apparatus for Measuring the Bursting Strength of Fabric.

CONDITIONING

The specimens may be subjected to any of the recognized methods of conditioning shown in the table below. In expressing the results of the bursting tests, the exact conditioning to which the material has been subjected must be stated.

CONDITIONING OF PAPERS BEFORE BURSTING TESTS

Condition.	Temp. °C.	Period in Controlled Atmosphere.	Relative Humidity.
Normal	15 to 25	18 hrs.	75%
Aged	110	24 hrs	Hot Oven
Prolonged ageing	110	7 days	" "
High temperature	120	24 hrs.	" "
Prolonged high temperature .	120	7 days	" "

METHOD OF TEST

No hard and fast rule is suggested here with regard to the type of bursting strength tester to be used ; but as the Mullen tester finds extensive use amongst paper manufacturers in Great Britain, and has been already suggested by the E.R.A. as a suitable apparatus for carrying out the tests developed by them, this form of apparatus is to be recommended to all who are about to put into use testing apparatus for bursting strength tests.

In expressing the results obtained on the bursting strength tester, the direction in which the paper fails relatively to the " machine direction " of the paper shall be stated. Bursting strength test results shall be expressed in lb. per square inch.

TEST No. 10

IMPACT (TOUGHNESS) TESTS

A. Applicable to—

Non-ignitable boards (E.R.A.), and varnish paper and varnish fabric boards (E.R.A.).

Also applicable to vulcanized fibre, slate, marble, and similar materials.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the impact test is carried out. In the case of Class D (non-ignitable boards), the temperature of conditioning shall be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

METHOD OF TEST (E.R.A.)

A specimen 3 in. long and 2 in. wide shall be cut from the board. The thickness of the specimen shall be the thickness of the material.

The specimen shall be subjected to test in an impact testing machine of the pendulum type. The natural surface of the material shall be in the plane at right angles to the direction of motion of the hammer.

The energy required to cause fracture, as indicated on the machine,

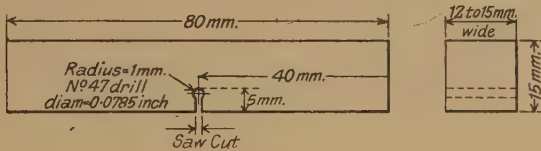


FIG. 53.

shall be expressed in ft.-lb., and the thickness of the specimen shall be stated.

B. Applicable to—

Hard composite dielectrics (E.R.A.).

CONDITIONING

The E.R.A. directions quote nine conditions in which it is recommended that hard composite dielectrics may be tested. For commercial test work, however, it is suggested here by the author that specimens should be subjected to *normal* conditioning before the test for impact strength is carried out.

METHOD OF TEST (E.R.A.)

Toughness shall be proved by an impact test carried out with a machine of the pendulum type, at a temperature of 15° C. to 20° C.

The form and dimensions of the specimen for sheet or rod material shall be as shown in Fig. 53. The notch shall take the form of a drilled

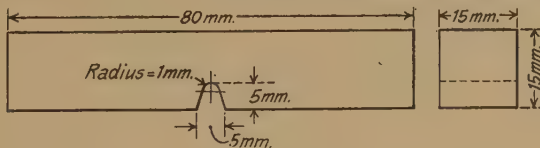


FIG. 54.

hole 1 mm. radius opened out to the side of the specimen by a saw cut. When it is impracticable to obtain sheet 15 mm. thick, the width of the specimen may be reduced to a minimum of 12 mm., the other dimensions remaining as in Fig. 53.

The form and dimensions of the specimen for moulded material shall be as shown in Fig. 54. The notch shall be moulded in.

As a certain number of materials may have different values for the

toughness depending on the direction of the blow with reference to the surface of the sheet, whenever possible impact tests shall be carried out with the blow delivered in directions parallel to, and at right angles to, respectively, the surface of the sheet. The velocity of the pendulum at impact shall be between 180 and 220 cm. per second. The minimum energy required to break the specimen shall be ascertained, and shall be expressed in kg.-cm.

Note. Whilst the specimen should be as nearly as possible of rectangular section, the bedding of the pendulum is improved by giving a slight curvature to the vertical edge of the supports, such that the point of contact of the specimen will be on the centre line of the latter. Small adjustments of the energy of the blow may be made by altering the velocity within the limits given above. Larger alterations have to be effected by changing the mass of the pendulum.

TEST No. 11

SHRINKAGE, WARPING, AND SWELLING TESTS

A. Applicable to—

Insulating materials in general, which are supplied in the form of boards, rods, and tubes.

Note. The E.R.A. has laid down definite rules for carrying out these tests on pressboard, vulcanized fibre, and varnish paper and varnish fabric products. The following directions are based on these rules.

CONDITIONING

Unless otherwise specified, all specimens shall be subjected to *normal* conditioning before the shrinkage, warping, and swelling tests are carried out.

METHOD OF TEST—SHRINKAGE TESTS

(a) *In Air.* In the case of boards, the test for shrinkage shall be carried out on a specimen 4 in. square. The length and width of the specimen shall be measured at ten points equally spaced along two edges at right angles. The thickness of the specimen shall be the mean of ten measurements of thickness taken at points equally spaced around the edges. The measurements shall be made by means of a micrometer or other suitable method.

In the case of tubes and rods, the test for shrinkage shall be carried out on a specimen, the length of which shall be not less than three times the external diameter.

The external diameter and, in the case of tubes, the internal diameter also shall be measured in two directions at right angles. In the case of products made from laminated boards (such as fibre rods, etc.), care must be taken to ensure that the measurements are made parallel to the laminae and perpendicular to the laminae. The measurements shall be made by means of a suitable micrometer.

The specimen shall then be dried for 48 hours by heating uniformly in an oven at a temperature of 105°C. to 110°C. In the case of Class I, Grade C, varnish paper products, this temperature should be raised to 160°C. to 165°C. ; whilst for Class II, Grade B, varnish paper products, the temperature should be lowered to 80°C. to 85°C.

The dimensions shall then be measured at the same point as before, as soon as the specimen has cooled down to room temperature.

Comparison shall be made between the mean values of the dimensions before and after the heat treatment, and the percentage difference, computed on the original mean values respectively, shall be stated, the mean values also being given.

SHRINKAGE TEST

(b) *In Hot Oil* (not applied to Class II, Grade B, varnish paper products). In the case of boards, the diameters of a ring cut from the board approximately 4 in. internal diameter and 6 in. external diameter shall be measured longitudinally and transversely. The specimen for carrying out tests on tubes and rods shall be identical with that outlined in (a) above.

The specimens, after being measured, shall be immersed for 120 hours in light grade insulating oil complying with B.E.S.A. Specification No. 148-(1923) at a temperature of 105°C. to 110°C. for vulcanized fibre and pressboard, 115°C. to 120°C. for all grades of varnish paper products except Class I, Grade C, which shall be immersed in mineral oil at a temperature of 170°C. to 175°C. and having a flash point not less than 250°C.

After removal from the oil, the specimen shall be remeasured as soon as it has reached room temperature.

Comparison shall be made between the mean values of the internal and the external diameters respectively before and after the immersion in oil, and the percentage differences computed on the original mean values shall be stated, the original mean values also being given.

METHOD OF TEST—WARPING

(c) *Boards.* A specimen 6 in. square shall be dried for 48 hours at the temperature indicated for the material in question in (a) above. It shall then be placed on a flat surface not less than 7 in. square, and a flat metal plate 6 in. square shall be placed on the specimen so that the edges of the plate and the specimen coincide. The weight of the upper plate shall not exceed 8 oz. The distances between the four corners of the under surface of the upper plate and the corresponding points on the surface of the lower plate shall be measured. The sum of the four readings shall be compared with four times the original mean thickness of the specimen before drying, and the percentage increase computed on four times the original mean thickness shall be stated.

METHOD OF TEST—WARPING

(d) *Tubes and Rods.* A straight sample of the tube or rod, the length of which shall be 24 times the internal diameter, shall be dried for 48 hours at the temperature indicated for the material in question in (a) above. The tube shall then be compared with a straight edge or tested by other suitable method to determine the maximum deviation from the straight. The maximum deviation thus determined shall be stated, and the internal and external diameters of the tube shall also be given.

METHOD OF TEST—SWELLING

(e) *Boards, Tubes, and Rods.* Specimens of the dimensions laid down in (a) above shall be exposed to an atmosphere at 100° C. and as near as possible 100 per cent humidity for a period of 6 hours. The dimensions of the specimens shall be measured before and after exposure to the humid atmosphere. The percentage difference in dimensions shall be computed on the mean thickness before the test is carried out, i.e. in the *normal* condition. The thickness of the material shall also be given.

TEST No. 12

COHESION BETWEEN LAYERS (SPLITTING TEST)

A. Applicable to—

Vulcanized fibre (E.R.A.) and varnish paper and varnish fabric products (E.R.A.).

Also applicable to other laminated insulating products.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the test for cohesion between layers is carried out. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

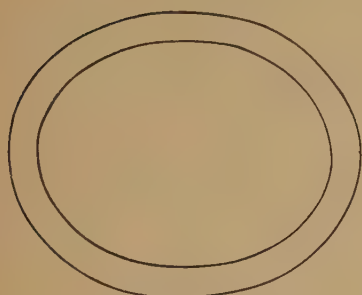
METHOD OF TEST

(a) *Boards* (E.R.A.). A specimen 1 in. wide and of a length equal to four times the thickness of the material, plus $\frac{1}{2}$ in., shall be supported on vee blocks spaced apart at a distance equal to four times the thickness of the material under test.

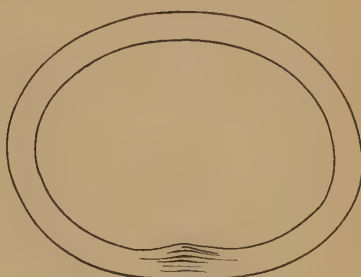
A load shall be applied centrally on the specimen and increased until failure occurs. The load required to cause failure and the nature of the fracture shall be stated.

(b) *Tubes* (E.R.A.). A specimen of the tube shall be cut of length equal to the external diameter, and shall be subjected to a crushing

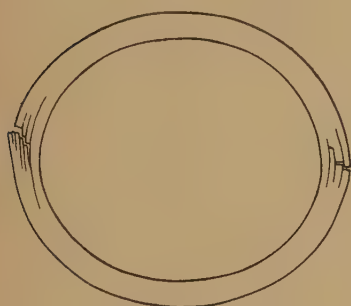
SPLITTING TEST ON INSULATING MATERIALS



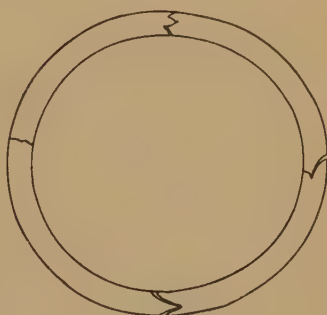
(a) Too flexible to show failure



(b) Splits easily



(c) Combines splitting and fracture



(d) Fracture before splitting occurs



(a) Too flexible to show failure



(b) Splits easily



(c) Combines splitting and fracture



(d) Fracture before splitting occurs

FIG. 55.—Showing the Nature of the Various Types of Failures met with in carrying out the Splitting Test.

load perpendicular to the axis of the tube. The load required to cause failure and the nature of the fracture shall be stated.

Note. Fig. 55 shows the nature of the various types of failures which may be anticipated in carrying out the above test, and the following terms are suggested as applicable to describing these failures. The standard specimen may be said to—

- (a) Be too flexible to show failure.
- (b) Split readily.
- (c) Have approximately equal resistance to splitting and fracture.
- (d) Fracture before splitting occurs.

TEST No. 13

DROPPING POINT OF BITUMINOUS MATERIALS BALL AND RING TEST

The following method is that developed by the American Society for Testing Materials (A.S.T.M.) and published by them under Serial Designation No. D36-21.

Proposed as tentative, 1916; adopted in amended form, 1919; revised, 1921.

1. The softening of bituminous materials generally takes place at no definite moment or temperature. As the temperature rises, they gradually and imperceptibly change from a brittle or exceedingly thick and slow flowing material to a softer and less viscous liquid. For this reason the determination of the softening point must be made by a fixed, arbitrary, and closely defined method if the results obtained are to be comparable.

I. APPARATUS

2. The apparatus shall consist of the following—

(a) *Ring.* A brass ring 15.875 mm. ($\frac{5}{8}$ in.) in inside diameter and 6.35 mm. ($\frac{1}{4}$ in.) deep; thickness of wall, 2.38 mm. ($\frac{3}{32}$ in.); permissible variation on inside diameter and thickness of ring, 0.25 mm. (0.01 in.). This ring shall be attached in a convenient manner to a No. 15 B. and S. gauge brass wire (diameter 1.79 mm. = 0.0703 in.). (See Fig. 1.)

(b) *Ball.* A steel ball 9.53 mm. ($\frac{3}{8}$ in.) in diameter, weighing between 3.45 and 3.55 g.

(c) *Container.* A glass vessel, capable of being heated, not less than 8.5 cm. (3.34 in.) in diameter and measuring 10.5 cm. (4.13 in.) in depth from the bottom of the flare. (A 600 cc. beaker, low form, meets this requirement.)

(d) *Thermometer.* A thermometer which shall conform to the following specifications—

Total length	370-400 mm. (14.57-15.75").
Diameter	6.5-7.5 mm. (0.256-0.295").
Bulb length	Not over 14 mm. (not over 0.55").
Bulb diameter	4.5-5.5 mm. (0.177-0.217").

The scale shall be engraved upon the stem of the thermometer, shall be clear cut and distinct, and shall run from 0° to 80° C. (32° to 176° F.) in $1/5^{\circ}$ C. divisions. It shall commence not less than 7.5 cm. (2.95 in.) above the bottom of the bulb. The thermometer shall be furnished with an expansion chamber at the top and have a ring for attaching

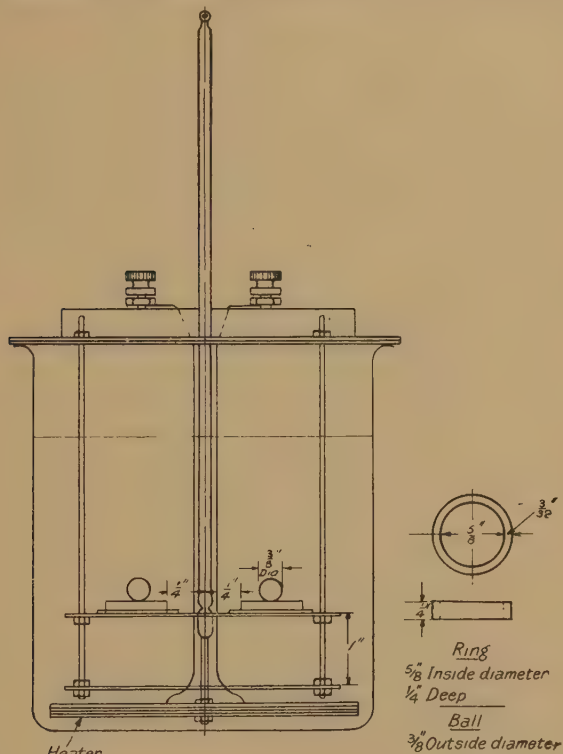


FIG. 56.—Bitumen "Dropping Point" Test Apparatus: Ball and Ring Method.

tags. It shall be made of a suitable quality of glass and be so annealed as not to change its readings under conditions of use. It shall be correct to 0.25° C. (0.45° F.), as determined by comparison at full immersion, with a similar thermometer calibrated at full immersion by the United States Bureau of Standards.

II. PREPARATION OF SAMPLE

3. The sample shall be melted and stirred thoroughly, avoiding incorporating air bubbles in the mass, and then poured into the ring so as to leave an excess on cooling. The ring, while being filled, should

rest on a brass plate which has been amalgamated to prevent the bituminous material from adhering to it. After cooling, the excess material shall be cut off cleanly with a slightly heated knife.

III. PROCEDURE

A. Bituminous materials having softening points 80° C. (176° F.) or below.

4. *Assembling.* Assemble the apparatus as shown in Figs. 56 and 57. Fill the glass vessel to a depth of substantially 8.25 cm. (3.25 in.) with freshly boiled, distilled water at 5° C. (41° F.). Place the ball in the centre of the upper surface of the bitumen in the ring and suspend it in the water so that the lower surface of the filled ring is exactly 2.54 cm. (1 in.) above the bottom of the glass vessel and its upper surface is 5.08 cm. (2 in.) below the surface of the water. Allow it to remain in the water for 15 min. before applying heat. Suspend the thermometer so that the bottom of the bulb is level with the bottom of the ring and within 0.635 cm. ($\frac{1}{4}$ in.) but not touching the ring.

5. *Heating.* Apply the heat in such a manner that the temperature of the water is raised 5° C. (9° F.) each minute.

6. *Softening Point.* The temperature recorded by the thermometer at the instant the bituminous material touches the bottom of the glass vessel shall be reported as the softening point.

7. *Permissible Variation in Rise of Temperature.* The rate of rise of temperature shall be uniform and shall not be averaged over the period of the test. The maximum permissible variation for any minute period after the first three shall be $\pm 0.5^\circ$ C. (0.9° F.). All tests in which the rate of rise in temperature exceeds these limits shall be rejected.

B. Bituminous Materials having softening point above 80° C. (176° F.)

8. *Modifications for Hard Materials.* Use the same method as given under *A*, except that glycerine shall be used instead of water, and that the thermometer shall conform to the following specifications—

Total length	370-400 mm. (14.57-15.75").
Diameter of stem	6.5-7.5 mm. (0.256-0.295").
Bulb length, not over	14 mm. (0.55").
Bulb diameter	4.5-5.5 mm. (0.177-0.217").

The graduations shall be from 30° to 160° C. in 0.5° C. and shall be clear cut and distinct. The 30° mark shall be at least 75 mm. above the bottom of the bulb. The length between the 30° mark and the 160° mark shall be between 230 and 275 mm.

The thermometer shall be furnished with an expansion chamber at the top and have a ring for attaching tags. It shall be made of a suitable quality of glass and so annealed as not to change its readings under conditions of use. It shall be correct to 0.25° C. as determined by comparison at full immersion with a similar thermometer calibrated at full immersion by the Bureau of Standards.

IV. PRECAUTIONS

9. The use of freshly boiled distilled water is essential, as otherwise air bubbles may form on the specimen and affect the accuracy of the results. Rigid adherence to the prescribed rate of heating is absolutely essential in order to secure accuracy of results.

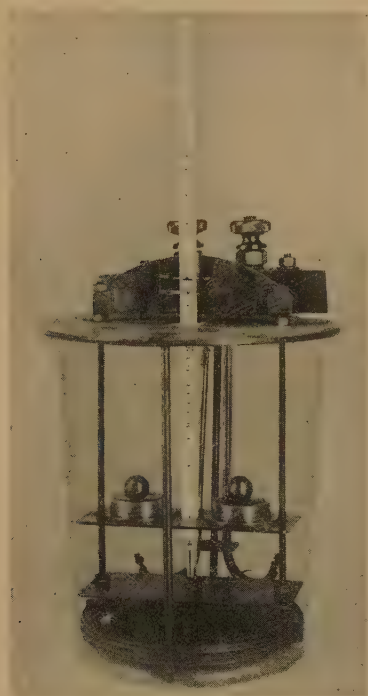


FIG. 57.—Bitumen "Dropping Point" Test Apparatus: Ball and Ring Method.

A sheet of paper placed on the bottom of the glass vessel and conveniently weighted will prevent the bituminous material from sticking to the glass vessel, thereby saving considerable trouble in cleaning.

V. ACCURACY

10. The limit of accuracy of the test is $\pm 0.5^{\circ}$ C. (0.9° F.).

TEST No. 14

VISCOSITY TESTS FOR FLUIDS

Viscosity tests for fluid dielectrics, varnishes, and solvents may be made, employing the Redwood Viscometer and the method described in Test No. 39.

TEST No. 15

PENETRATION TEST ON BITUMENS

Applicable to—

Bituminous and cable compounds.

NEEDLE PENETROMETER TEST AS STANDARDIZED BY THE
AMERICAN SOCIETY FOR TESTING MATERIALS

Penetration here is defined as: The consistency of a bituminous material, expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time, and temperature. Where the conditions of test are not specifically mentioned, the load, time, and temperature are understood to be 100 g. 5 sec., and 77° F. respectively, and the units of penetration to indicate hundredths of a centimetre.

The container for holding the material to be tested shall be a flat-bottom cylindrical dish $2\frac{3}{16}$ in. in diameter and $1\frac{3}{8}$ in. deep. The needle for this test shall be a cylindrical steel rod 2 in. long, having a diameter of 0.04 in. and turned on one end to a sharp point, having a taper of $\frac{1}{4}$ in. The point is then ground off to give a flat end 0.0055 to 0.0063 in. diameter. The water bath shall be maintained at a temperature not varying more than 0.2° F. from 77° C. The volume of water shall not be less than 10 litres, and the sample shall be immersed to a depth of not less than 4 in. and shall be supported on a perforated shelf of not less than 2 in. from the bottom of the bath. Any apparatus which will allow the needle to penetrate without appreciable friction, and which is accurately calibrated to yield results in accordance with the definition of penetration, will be acceptable. The transfer dish for container shall be a small dish or tray of such capacity as will ensure complete immersion of the container during the test. It shall be provided with some means which will ensure a firm bearing and prevent rocking of the container. The sample shall be completely melted at the lowest possible temperature and stirred thoroughly until it is homogeneous and free from air bubbles. It shall then be poured into the sample container to a depth of not less than $\frac{5}{8}$ in. The sample shall be protected from dust and allowed to cool in an atmosphere not lower than 65° F. for 1 hr. It shall then be placed in the water bath, along with the transfer dish, and allowed to remain 1 hr.

In making the test, the sample shall be placed in the transfer dish, filled with water from the water bath at sufficient depth to completely cover the container. The transfer dish containing the sample shall then be placed upon the stand of the penetration machine. The needle, loaded with specified weight, shall be adjusted to make contact with the surface of the sample. This may be accomplished by making contact of the actual needle point with the image reflected by the surface of the sample from a properly placed source of light. Either

the reading of the dial shall then be noted, or the needle brought to zero. The needle is then released for the specified period of time, after which the penetration machine is adjusted to measure the distance penetrated. The apparatus is shown in Fig. 58.

At least three tests shall be made at points on the surface of the sample not less than (1 cm.) $\frac{3}{8}$ in. from the side of the container, and not less than $\frac{3}{8}$ in. apart. After each test the sample and transfer dish are returned to the water bath and the needle shall be carefully wiped towards its point with a clean dry cloth, to remove all adhering bituminous matter. The reported penetration shall be the average of at least three tests, whose values shall not differ more than 4 points between maximum and minimum. When desirable to vary the temperature, time, and weight, and to provide for uniform method of reporting results when such variations are made, the sample shall be melted and cooled in air as above directed. It shall then be immersed in water or brine as the case may require, for 1 hr. at the temperature desired. The following combinations are suggested—

32° F. .	200 g. weight ;	60 sec.
77° F. .	100 g. weight ;	5 sec. ¹
115° F. .	50 g. weight ;	5 sec.

The principal shortcoming of the needle penetrometer is the fact that the readings at various temperatures (115, 77, and 32° F. respectively) must be expressed on different scales, and are therefore not comparable. It is difficult and in many cases impossible to interpret the extent of the physical change from the range in readings upon subjecting a bituminous substance to variations in temperature. In addition, the scope of the penetrometer is limited, as it will not answer for either semi-liquid or hard bituminous materials.

TEST No. 16

SOFTENING POINT TEST

A. Applicable to—

Varnish paper and varnish fabric products (E.R.A.).

Also applicable to moulded composition and other insulating materials liable to become plastic at temperatures met with normally in electrical machinery.

CONDITIONING

Unless otherwise stated, the specimen shall be subjected to *dry* conditioning before the test for softening point is carried out. In the case of hard rubber (ebonite, etc.), and of Class D non-ignitable boards,

¹ Suggestion by H. Abraham in *Asphalts and Allied Substances*. Not included in the printed method published by the Am. Soc. Testing Materials.

the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A. Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.) and Class D non-ignitable boards for the purposes of this test.

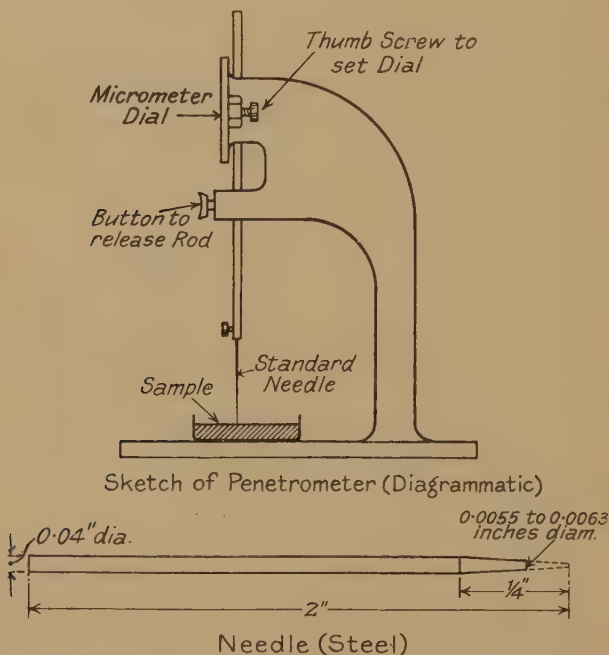


FIG. 58.—Sketch of Penetrometer.

METHOD OF TEST

(a) *Boards* (E.R.A.). The softening point of the material shall be determined on a specimen of dimensions similar to those of the specimen employed in the Stiffness or Rigidity Test No. 6. The specimen shall also be set up in a manner similar to that employed in the Stiffness or Rigidity Test.

A load equal to half the value of the load employed in the 18 hr. Stiffness or Rigidity Test shall then be applied. The apparatus shall be arranged in a suitable heated chamber, the temperature of which shall be gradually increased at the rate of 10° C. per hour until the specimen

fails completely. The initial temperatures (in the case of varnish paper and varnish fabric products) shall be as follows—

- (i) For Class I (synthetic) materials, 100° C.
- (ii) For Class II (natural resins, etc.) materials, 60° C.

The deflection at each 5° C. increment of temperature shall be noted, and the complete failure shall be deemed to have occurred when the rate of deflection of the specimen is seen to increase rapidly without appreciable increase of temperature.

METHOD OF TEST

(b) *Tubes* (E.R.A.). The softening point of the material shall be determined on a specimen of dimensions similar to those of the specimen employed in the Stiffness or Rigidity Test on Tubes (Test No. 6).

The specimen shall be set up for test in a manner similar to that described in Test No. 6.

A load equal to half the value of the load at which failure occurs in Test No. 6 shall be applied. The test shall then be carried out in the same manner as described in (a) above.

TEST No. 17

CHARRING (FUSE WIRE) TEST

A. Applicable to—

Non-ignitable boards and mouldings (E.R.A.), varnish paper, and varnish fabric products (E.R.A.).

Also applicable to vulcanized fibre, fireproof treated timbers, moulded compositions, and similar materials.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the test for charring is carried out. In the case of hard rubber (ebonite, etc.), and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.) and Class D, non-ignitable boards.

METHOD OF TEST (E.R.A.)

The specimen shall consist of two pieces of the material, each 7 in. (175 mm.) long, 2 in. (50 mm.) wide, and not less than $\frac{3}{16}$ in. (5 mm.)

thick, clamped together by two bolts 6 in. (150 mm.) apart, the latter acting as terminals for the fuse wire. The fuse shall consist of a 0.036 in. (0.914 mm.) diameter copper wire laid centrally between the two pieces of the material, the general arrangement being shown in Fig. 59.

The wire shall be fused by being switched across a 500 V. D.C. circuit, in which there is a total non-inductive resistance of such a value as to limit the current to 100 amperes.

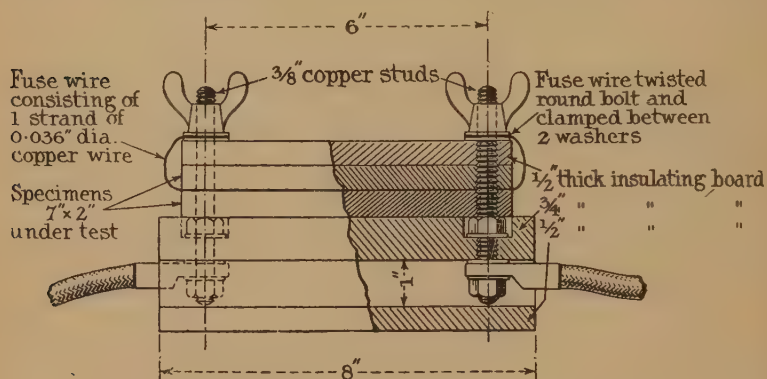


FIG. 59.—Apparatus for the Charring (Fuse Wire) Test.

The test shall be repeated on the same specimen at intervals of 2 minutes, until the material fails to extinguish the arc or its surface fuses, disintegrates, or carbonizes. The number of tests the fuse may be blown before this state is reached, and the condition of the surface, shall be recorded. If no disintegration has taken place after 10 tests, the condition shall be recorded at this stage. For acceptance tests on materials for specific purposes, the number of applications of the test which the material must withstand without a well defined change shall be stated.

TEST No. 18

CHARRING (CARBON ARC) TEST

A. Applicable to—

Non-ignitable boards and mouldings (E.R.A.).

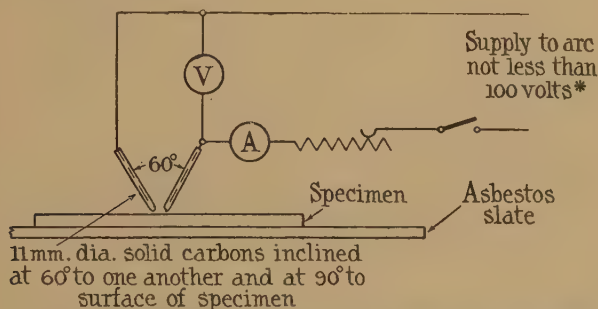
Also applicable to moulded compositions and materials of a fireproof, partially fireproof, or fire-resisting nature which are liable to become exposed to an electric arc.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the test for charring is carried out. In the case of

hard rubber (ebonite, etc.), and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40°C. to 45°C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55°C. to 60°C.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.) and Class D non-ignitable boards.



NOTE:- With 240 volts an arc of 3 mm. can be struck and maintained quickly and steadily, and this voltage is recommended for use whenever convenient.

FIG. 60.—Apparatus for Charring (Carbon Arc) Test.

METHOD OF TEST (E.R.A.)

The specimen shall consist of a flat sheet of the material. For testing the properties of a given material, the sample shall not be less than $\frac{3}{16}$ in. (5 mm.) thick. When using thinner material for a given purpose, the sample tested should be of the thickness employed for that purpose. In the case of moulded materials, a specimen offering a suitable surface shall be employed.

The specimen shall be placed on a horizontal base of asbestos slate or other similar heat insulating material.

The arc shall be obtained between two solid carbons 11 mm. diameter, inclined at an angle of 60° to each other, with their plane set at an angle of 90° to the surface of the specimen, the carbons being arranged to travel just clear of the surface of the specimen. The arc is blown on to the specimen by the magnetic field established by the current in the inclined carbons.

The supply to the arc shall be connected through a switch, an adjustable resistance, and an ammeter. A voltmeter shall be connected across the arc. The general arrangement of the test is shown in Fig. 60.

The carbons shall be operated by hand, the arc struck and quickly

adjusted to 10 amperes and 45 volts, being maintained steadily at this value, which corresponds to an arc length of approximately 3 mm.

For research tests, the effect of exposing the specimen to the arc for 15, 30, 60 sec., and, if necessary, for longer periods, may be recorded. For acceptance tests on materials for a specific purpose the duration of applications of the arc shall be stated.

Note.—The mechanisms and fittings of arc lamps sold for use in projection lanterns will be found suitable for the purpose.

TEST No. 19

IGNITION (RADIANT HEAT) TEST

A. Applicable to—

Non-ignitable boards and mouldings (E.R.A.).

Also applicable to vulcanized fibre, varnish paper and varnish fabric products, fireproof treated timbers, moulded compositions, and other insulating materials in general.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the radiant heat test is carried out. In the case of hard rubber (ebonite, etc.), and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.) and Class D non-ignitable boards.

METHOD OF TEST (E.R.A.)

The specimen shall be $\frac{1}{2}$ in. ($12\frac{1}{2}$ mm.) wide, 2 in. (50 mm.) long, and of thickness equal to the thickness of the material, provided it is not more than $\frac{1}{2}$ in. ($12\frac{1}{2}$ mm.) thick. If the thickness of the material is over $\frac{1}{2}$ in. ($12\frac{1}{2}$ mm.), the specimen shall be cut down to $\frac{1}{2}$ in. thick.

The specimen shall be suspended in the apparatus shown in Fig. 61 so that its upper end is $5\frac{1}{2}$ in. (140 mm.) below the top of the tube. The pilot flame shall be arranged $\frac{3}{4}$ in. (19 mm.) above the upper end of the specimen. The air shutter shall be kept closed.

The temperature of the tube shall then be uniformly increased at the rate of 300° C. per hour, and the temperature at which the material ignites shall be noted. When the material has ignited, the specimen shall be lowered into the lower part of the apparatus, to the level indicated in Fig. 61, and it shall be noted whether or not the material

continues to burn. For this latter part of the test, the air shutter shall be open.

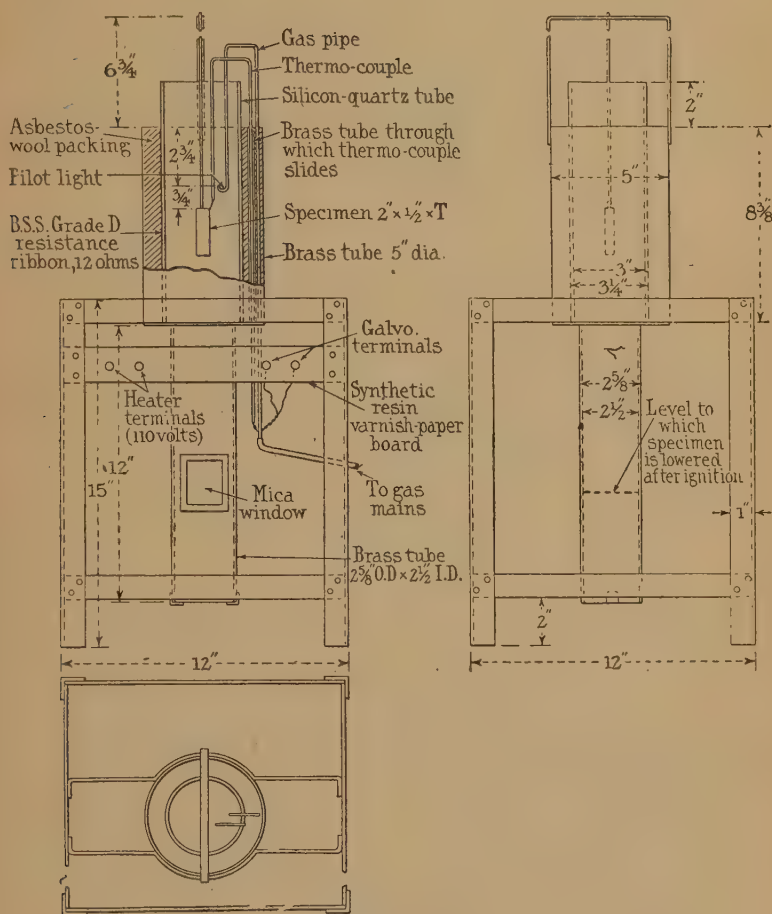


FIG. 61.—Arrangement of Ignition (Radiant Heat) Test.

Note.—This apparatus was originally devised and recommended by the Forest Products Laboratory, Madison, U.S.A. The current required to produce the temperature rise specified is approximately 9 amperes.

TEST No. 20

IGNITION (MEKER BURNER) TEST

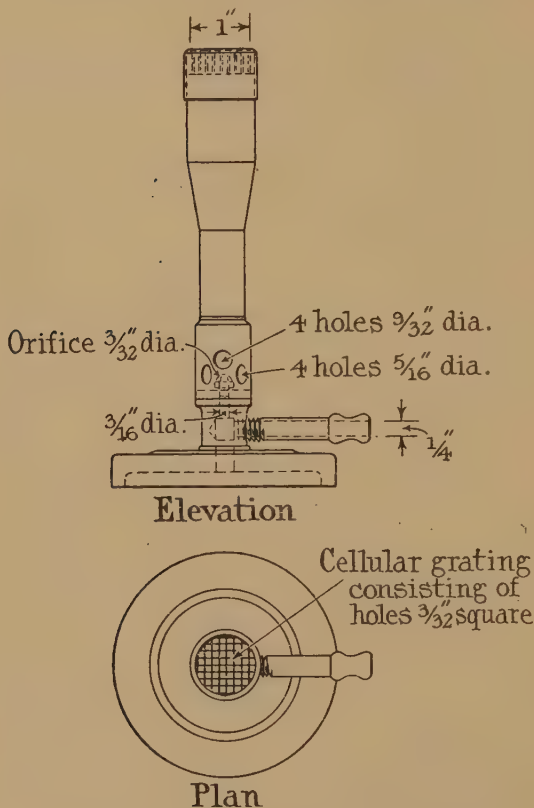


FIG. 62.—Meker Burner for Ignition Test.

A. Applicable to—

Non-ignitable boards and mouldings (E.R.A.).

Also applicable to vulcanized fibre, varnish paper and varnish fabric products, moulded compositions, fireproof treated timbers, special hard rubber products, and other hard dielectrics.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the ignition test is carried out. In the case of

hard rubber (ebonite, etc.), and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing rubber and bitumen shall be

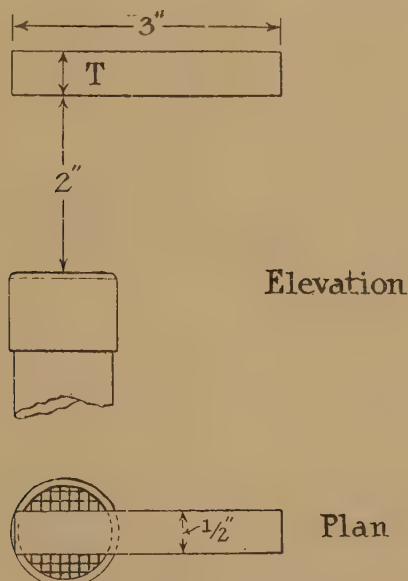


FIG. 63.—Arrangement of Specimen for Meker Burner Test.

regarded in the same category as hard rubber (ebonite, etc.) and Class D non-ignitable boards.

METHOD OF TEST (E.R.A.)

The specimen shall consist of a piece of the material 3 in. (75 mm.) long, $\frac{1}{2}$ in. (12½ mm.) wide, and of thickness equal to the thickness of the material. The specimen shall be supported in the flame of a 1 in. Meker burner of the dimensions shown in Fig. 62. It shall be placed with its axis horizontal and with the $\frac{1}{2}$ in. dimension (12½ mm.) facing the flame and 2 in. (50 mm.) above the top of the burner, the end plane of the specimen being vertically above the edge of the burner as shown in Fig. 63.

The calorific value of the gas used must be known, and shall be between 400 and 600 B.Th.U. per cubic foot.

The time before the specimen ignites shall be noted, and the constant K of the material shall be calculated from the following formula—

$$K = \frac{tc}{500A} \text{ Perimeter (inches) minus one horizontal side (inches)}$$

where .

- t = time in seconds before the specimen ignites.
- c = calorific value of gas in B.Th.U.'s per cubic foot.
- A = cross-sectional area of specimen in square inches.

TEST No. 21

WATER ABSORPTION TESTS

A. Applicable to—

Pressboards (E.R.A.), vulcanized fibre (E.R.A.).

Varnish paper and varnish fabric products (E.R.A.).

Non-ignitable boards and mouldings (E.R.A.).

Also applicable to untreated and treated timbers, slate, marble, substitutes for slate and marble, and similar materials.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the test for water absorption is carried out. In the case of hard rubber (ebonite, etc.), and of Class D non-ignitable boards, the temperature of conditioning shall be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

METHOD OF TEST (E.R.A.)

A specimen 1½ in. square, and of thickness equal to the thickness of the material as supplied, or, in the case of tubes, a piece 1½ in. long cut from the tube, shall be weighed. Specimens prepared from boards shall have the four edges freshly cut before being tested. Similarly, the two ends of tube specimens shall be freshly cut. The specimen shall be immersed in water at a temperature from 15° C. to 20° C. After 24 hours' immersion it shall be taken from the water, and after removing the surface moisture by wiping, weighed again.

The specimen shall then be replaced in the water and, after 6 days' immersion, re-weighed with the same precautions as before. The weight shall be taken to the nearest milligramme in each case.

The percentage absorption of water in each case shall be computed on the original weight of the specimen, and the original thickness of the specimen shall be stated.

When it is desired to determine the absorption in the direction normal to the surface of the material, the edges of the specimen shall

be coated with a waterproof varnish before the water absorption test is carried out.

B. Applicable to—

Moulded compositions (hard composite dielectrics. E.R.A.).

CONDITIONING

Unless otherwise specified, specimens shall be conditioned as above outlined, i.e. *dry* conditioned.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.) and Class D non-ignitable boards in respect to conditioning.

METHOD OF TEST

The test shall be carried out exactly as above, except that the size of the sample has been defined by the E.R.A. in Technical Publication B/S1 as 5 cm. square and 5 mm. thickness. It is suggested here, however, that it is not always possible or desirable to employ a sample of this size, particularly in the case of tubes, thin sheets, etc., and therefore the sizes of specimen laid down in *A* above will be found to be of greater practical use. It is further suggested that small moulded articles with a total surface area not exceeding 6 sq. in. shall be tested intact. Larger irregular shaped articles shall be cut to give the specimens a surface area of 6 sq. in. Any protective coating of varnish or enamel shall be removed before the tests are made, unless otherwise stated.

C. Applicable to—

Porcelain (B.E.S.A.).

Also applicable to earthenware, steatite products, porcelain cements, and similar products.

CONDITIONING

The B.E.S.A. Specification No. 137—1922, Porcelain Insulators for Overhead Power Lines, does not specify the conditioning to which samples should be submitted before test, but it is suggested here that the E.R.A. *normal* conditioning should as a general rule be employed.

METHOD OF TEST

The above-mentioned B.E.S.A. specification states that—

The finished porcelain shall show no signs of impregnation when broken pieces (selected free from any of the external glaze) are immersed for 24 hr. in a 0.5 per cent solution of fuchin under a pressure of 2,000 lb. per square inch (140 kg. per sq. cm.).

It is suggested, however, that where possible two specimens should be tested, one with unbroken glazed surface and the other free from external glaze as specified by the B.E.S.A. specification. The extent to which the dye has penetrated the material is judged by breaking

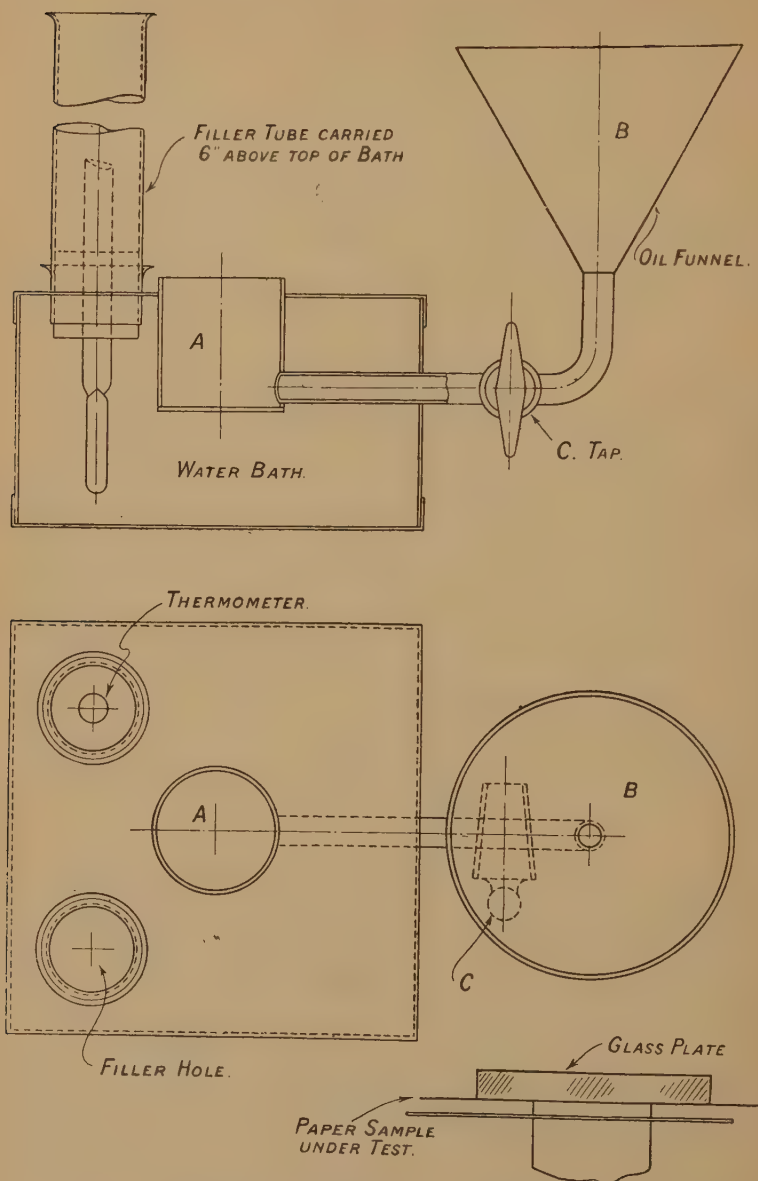


FIG. 64.—Apparatus for Carrying Out Water Absorption Tests.

the sample after immersion. The average depth to which the red dye is visible from the glazed surface in one case, and from the fractured surface in the second case, should be recorded. Where the testing facilities available do not permit a pressure of 2,000 lb. per sq. in. being maintained, a lower pressure may frequently prove sufficient to eliminate excessively porous materials.

D. Applicable to—

Untreated papers (E.R.A.).

CONDITIONING

The specimens shall be subjected to *normal* conditioning before the test for water absorption is carried out.

METHOD OF TEST (E.R.A.)

The absorption of the paper shall be determined on samples 3 in. square by means of the apparatus shown in Fig. 64 and described below.

A is a cylindrical brass vessel 1 in. in internal diameter, connected to the funnel *B* through the tap *C*. The cylinder is surrounded by a water bath for temperature control, and for carrying out the test the whole is placed over a bunsen burner.

To carry out a test, oil is introduced into the funnel until a meniscus is formed above the upper edge of the cylinder *A*. Square samples of paper and a piece of plate glass $\frac{1}{4}$ in. thick and 2 in. square are laid over the upper end of *A*. The time that elapses up to the whole of the paper surface, as seen through the glass square, becoming impregnated shall be taken as a measure of the absorption of the sample.

The temperature of the water bath shall be 40° C., and pure rape oil having a viscosity of 0.55 poise at this temperature shall be used.

The absorption test shall be carried out on 10 specimens taken from positions 5 in. apart located across the width of the roll or sheet. When the width of the roll or sheet is insufficient to enable 10 specimens to be cut from one strip, two or more strips shall be tested.

As most papers have two values for absorption depending upon the direction of flow of oil through the paper, tests shall be taken, first with one side downwards and then the other, and the average of the 10 results for each recorded. The absorption number of the paper shall be the reciprocal of the mean of the average values for the two sides of the paper multiplied by 100.

Note.—It should be clearly understood that the Water Absorption Test on Untreated Papers bears no relation whatever to the Porosity Test No. 22 as applied to papers. Two papers with the same water absorption number may show porosity numbers differing more than 100 per cent from one another, depending on the class of raw fibres employed, sizing, and "make."

E. Applicable to—

Insulating varnishes (E.R.A.).

Note.—The E.R.A. describes this test as “Water Permeability Test.”

No special *conditioning* of the varnish is called for before the test is commenced.

METHOD OF TEST (E.R.A.)

A clean, smooth, copper or brass sheet approximately 10 in. square and 5 mils thick shall be coated on one side only, either by spraying or pouring the varnish over the sheet. The density and viscosity of the varnish shall be adjusted in accordance with conditions specified by the varnish maker.

The thickness of the film shall be measured at 20 points equally spaced over the area of the sheet. The thickness at any point shall not vary from the mean value by more than 1 mil, and the mean value shall be taken as the thickness of the varnish film. In each quarter of the sheet a ring of wax approximately $2\frac{1}{2}$ in. internal diameter and $\frac{1}{8}$ in. deep shall be made on the varnish. The four rings shall be filled with distilled water and left for a period of 24 hours. The water shall then be removed as far as possible with a pipette, the remainder being absorbed by blotting paper or similar material. The sheet shall be left for 5 min. to dry off at a temperature from 20° C. to 25° C. The electrical strength of the varnish shall then be determined at two positions in each quarter of the sheet, one inside the ring of wax and the other outside, but as close to the ring as possible, care being taken that the varnish surface on which the electrode is placed is entirely free from wax.

The upper electrode shall be a solid cylinder of brass $1\frac{1}{2}$ in. long and $1\frac{1}{2}$ in. diameter. The electric strength test shall be carried out at a temperature from 20° C. to 25° C. In other respects the electric strength test shall be carried out in accordance with abridged directions for determining the electric strength of insulating materials. (Appendix II.)

Comparison shall be made between the mean values of the four puncture voltages inside and outside the rings respectively, and the percentage decrease computed on the mean outside value shall be stated.

F. Applicable to—

Insulating varnishes (E.R.A.).

Note.—The E.R.A. describes this test, “Test for Resistance to Moisture.”

CONDITIONING

No special conditioning is called for before this test is carried out.

METHOD OF TEST (E.R.A.)

The ability of the varnish to resist moisture shall be determined by

carrying out the electric strength test as directed in Appendix II, after the specimen has been subjected to an approximately saturated atmosphere (relative humidity not less than 95 per cent) for a period of 3 days. The electric strength test shall be carried out whilst the specimen is in the moist atmosphere, at a temperature from 20° C. to 25° C.

TEST No. 22

POROSITY TEST

A. Applicable to—

Electrical Insulating Papers (E.R.A.).

CONDITIONING

The specimens shall be subjected to *normal* conditioning before the porosity test is carried out.

METHOD OF TEST (E.R.A.)

The porosity of the paper shall be determined by means of the following apparatus, which shall be assembled as shown in Fig. 65—

(a) Glass burette graduated 0 to 100 c.c. (length of 100 c.c. graduations approximately 22 in.) and fitted with a stop cock at the top.

(b) Two metal clamping discs having a 1 in. recess (with smaller hole tapped into it to take connection to burette) in one disc and a 1 in. hole in the other. The inner side of each disc shall be faced with rubber sheet $\frac{1}{8}$ in. thick.

(c) Aspirator bottle approximately 300 c.c. and 2½ in. diameter, fitted with a rubber tube connection at the bottom.

(d) Three feet of rubber tubing, internal diameter $\frac{3}{16}$ in. and external diameter $\frac{7}{16}$ in.

(e) Ring stand approximately 4 ft. high.

The test shall be carried out as follows—

Open the stop cock of the burette and place the aspirator bottle in the upper support. The bottle shall contain sufficient water and the upper support shall be so adjusted that when the surface of the water in the burette coincides with the zero mark the depth of the water in the bottle is about 1 in.

A strip of paper 2½ in. wide shall be cut from the roll or sheet. The length of the strip shall be equal to the full width of the roll or sheet. The strip of paper shall be clamped between the rubber-faced metal discs, the stopcocks closed, and the bottle lowered until the surface of the water in it is 24 in. below the zero mark of the burette. The stopcock shall then be opened and allowed to remain open until 100 c.c. of water have flowed out of the burette. The time required for the discharge of 100 c.c. of water shall be measured by means of a stop watch or other suitable instrument.

The porosity number of the paper shall be the reciprocal of the number of seconds required for the discharge of the water multiplied by 100.

The porosity of the paper shall be measured at 10 points 5 in. apart, located across the width of the roll or sheet.

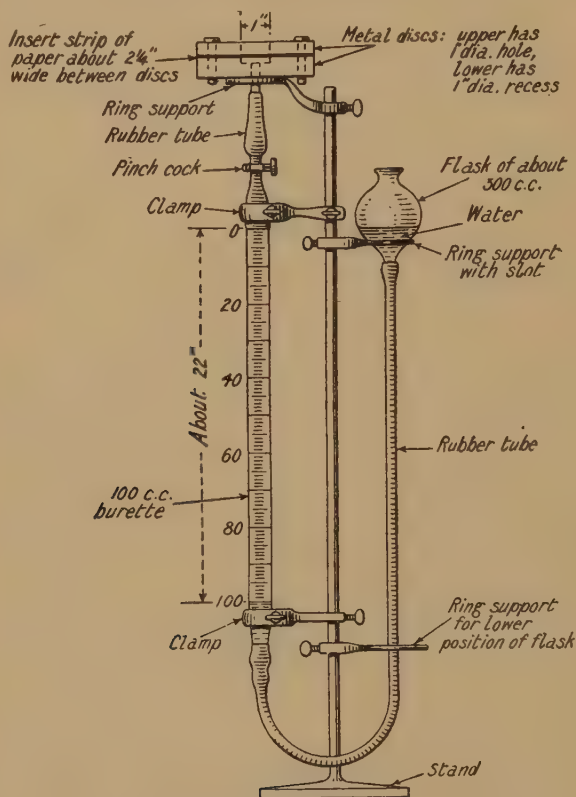


FIG. 65.—Apparatus Used for Porosity Tests.

The maximum, minimum, and mean values of the porosity number shall be stated.

When the width of the roll or sheet is insufficient to allow 10 tests to be made on one strip, two or more strips shall be tested.

TEST No. 23

EFFECTS OF ACIDS AND ALKALIS

A. Applicable to—

Insulating varnishes. (E R.A.).

CONDITIONING

No special conditioning is called for before the tests for determining the effect of acids and alkalis are carried out. The varnish samples employed shall be taken from the bulk according to the directions quoted in Test No. 32.

METHOD OF TEST (E.R.A.)

The ability of the varnish to withstand the effect of acids and alkalis shall be determined at a temperature between 15° C. and 25° C. by the following tests—

(a) A number of copper rods each approximately $\frac{1}{4}$ in. diameter and about 6 in. long (with one end rounded and the other suitably provided with means for suspending and leading an electrical connection to it) shall be prepared for the test by brightly burnishing, washing in dilute alcohol, and then drying in warm air.

Whilst still warm the rod shall be dipped carefully (without agitation) into the varnish and then dried in accordance with the directions given in E.R.A. Tech. Publ. A/S9, quoted on pages 284-5, footnote.

When dry the rounded end of each rod shall be coated with paraffin wax to a distance of approximately 2 cm.

A zinc rod, such as used in Leclanche cells, shall be well amalgamated with mercury and immersed centrally in a vessel containing a 25 per cent solution of sulphuric acid (4 volumes of water to 1 volume of concentrated sulphuric acid—specific gravity of the solution, 1.14). The lower end of the zinc rod shall dip into a small cup containing mercury (in order to maintain the amalgamation), whilst the copper rods shall be arranged around the zinc rod at a radius of 5 cm. The zinc rod shall be connected to one terminal of a millivoltmeter, while each of the copper rods shall be successively connected up and the potential difference noted.

The millivoltmeter used shall have a range of 1,500 millivolts and a resistance of 60 ohms (plus or minus 10 per cent) at 20° C. If an instrument of lower resistance be used, then a resistance shall be inserted in series to make up the difference, and the readings multiplied by a correction factor to give the millivolts across the instrument and external resistance. If an instrument of higher resistance be used it shall be shunted, and the readings multiplied by a suitable correction factor.

It is important that no difference of potential is indicated at the commencement, and should any occur the rod shall be rejected and a fresh one put in its place. The rods shall be tested every hour for the first few hours to study the effect, and then at intervals of 6, 12, or 24 hours.

(b) The varnish shall be tested as described in (a), except that the solution in which the rods are immersed shall be a 10 per cent solution of caustic soda (NaOH) prepared with distilled water (specific gravity equals 1.13).

(c) A standard Soxhlet thimble, approximately 20 mm. by 8 mm. (as made by Whatman, or similar thimble) shall be coated with two coats of the varnish under test, either by dipping or brushing, and shall then be dried in accordance with Clause 13 (a).¹ It shall be filled to within $\frac{1}{2}$ in. of the top of the varnish film with a 10 per cent solution of caustic soda (NaOH). It shall be then supported by suitable means in a freshly prepared solution of phenolphthalein in distilled water, dipping to the same level as the alkali inside. The time, expressed in minutes, taken for the solution in the immediate vicinity of the thimble to turn pink in colour, due to the alkali, shall be noted.

(d) The following tests shall be carried out on sheet copper specimens about 5 mils thick and $\frac{3}{4}$ in. wide. The specimens shall be varnished and dried as specified in Clause 13 (a).¹

¹ Paragraph 13a of E.R.A. Technical Publication A/S9, reads as follows—

DRYING OF SURFACE FILM

The test shall be carried out on either Japanese Gampi tissue paper approximately 1 mil thick, or on sheet copper or brass about 5 mils thick. The dimensions of the specimen shall be approximately 8 inches long and 6 inches wide.

(i) *Preparation of Specimens.* The density of the varnish to be employed for the drying test shall be so adjusted by trial with the thinner recommended by the varnish manufacturer that the thickness of the varnish film on each side of the paper or metal sheet shall be not less than 3 mils, and not more than 3.5 mils, in the vicinity of the centre of the specimen.

To obtain the required thickness of film the varnish shall be diluted with the solvent recommended by the varnish manufacturer, and the paper or metal shall be varnished as follows—

To determine the correct density of the varnish, strips of paper or metal shall be dipped in samples of diluted varnish containing amounts of thinner ranging from 5 per cent to 50 per cent (by volume). After draining for 30 minutes at room temperature, approximately 20° C., the specimen shall be dried as specified in (ii) below. Each specimen shall then be dipped again in varnish of the same density as before, drained for 30 minutes at room temperature, and dried as specified in (ii) below. During the draining, care shall be taken that the specimens remain stationary. When being dipped, drained and dried the second time the specimens shall be suspended in the opposite direction to that employed for the first film. The depth of the varnish in which the specimen is dipped shall be about $\frac{3}{4}$ inch, and the specimen shall be immersed completely for approximately 1 minute, care being taken to remove all froth. The specimen shall be drawn through the varnish at the same rate as the excess of varnish slips from the surface of the specimen.

Note.—If none of the specimens is of the specified thickness, the required density of the varnish may be obtained by interpolation.

(ii) *Method of Drying.* Six specimens coated with air-drying varnish shall be dried in free air at a temperature from 20° C. to 25° C.

Six specimens shall be dipped in baking varnish as specified in (i) above, and allowed to drain for 30 minutes at room temperature, approximately 20° C., and then dried in an oven heated externally at a temperature from 95° C. to 100° C., unless the varnish manufacturer recommends a higher temperature. The air content of the oven shall be changed completely not less than three times per hour. After the first coat has been dried the specimens shall be removed from the oven and allowed to cool to air temperature, approximately 20° C.; they shall then be dipped a second time and drained and dried as before. When being dipped, drained and dried the second time

The specimens shall be immersed in the reagents given below at a temperature from 15° C. to 25° C. for approximately 16 hours, and suspended in an air oven at atmospheric temperature for the remainder of the 24 hours. This procedure shall be carried out for six days consecutively, and the effect of the reagents on the varnish shall be stated.

Reagents—

Sulphuric acid, specific gravity 1.4.

Hydrochloric acid, specific gravity 1.1.

Nitric acid, 5 per cent solution.

Picric acid, 2.5 per cent aqueous solution.

Ammonia (0.88), 10 per cent solution.

Mixture of ammonium chloride and sulphate, a saturated aqueous solution.

Caustic soda, specific gravity 1.13 (10 per cent NaOH).

B. Applicable to—

Varnish paper and varnish fabric products (E.R.A.).

CONDITIONING

The tests for the effect of acids and alkalis shall be carried out on the material as received without conditioning.

METHOD OF TEST (E.R.A.)

The specimens shall be 1 in. wide and of length equal to four times the thickness of the material plus $\frac{1}{2}$ in. They shall be immersed in the following reagents—

(a) A sulphuric acid solution, specific gravity 1.25 for 24 hours at a temperature of 40° C. .

(b) A 5 per cent solution of caustic soda for 24 hours at a temperature of 100° C. (This test is not applicable to materials made with natural resin and gum varnishes.)

(c) A 10 per cent solution of common salt for 24 hours at a temperature of 100° C.

After removal from the reagents the specimens shall be tested for cohesion between layers in accordance with Test No. 12, and their condition with respect to disintegration, blistering, warping, splitting, or other deterioration shall be stated.

the specimens shall be suspended in the opposite direction to that employed for the first film.

The first specimen shall be tested as specified in (iii) below, 30 minutes before the expiration of the time stated by the varnish manufacturer, and thereafter further specimens shall be tested similarly at intervals of 10 minutes.

(iii) *Time of Drying.* The varnish shall be considered dry when a circular piece of No. 4 Whatman filter paper $1\frac{3}{8}$ inch diameter does not adhere to the varnish when it is pressed on the surface of the varnish for one minute by a cylindrical weight of 1 lb., 1 inch in diameter. The filter paper shall be applied in the vicinity of the centre of the specimen. The test shall be carried out at a temperature from 15° C. to 25° C.

TEST No. 24**EFFECT OF OIL**

A. Applicable to—

Insulating varnishes (E.R.A.).

CONDITIONING

No special conditioning is called for before the test for the effect of oil is made. The test sample shall be taken from the bulk in accordance with the directions given in Test No. 32.

METHOD OF TEST (E.R.A.)

The ability of the varnish to withstand hot oil shall be determined by the following tests—

(a) Specimens of rope paper shall be varnished and dried as specified in Test No. 32; the paper shall be in accordance with the rope paper defined in Technical Publication (of the E.R.A.) Ref. A/S5.

The effect of oil on the varnish shall be determined by immersing a number of varnished specimens in oils specified below at a temperature from 115° C. to 120° C. The specimens shall be examined at intervals, and the period required for the varnish to be affected by the oils shall be determined. Any such effect as the formation of sludge, etc., on the varnish film shall be recorded.

The oils employed shall be—

(i) Transformer oil, complying with B.E.S.A. Specification No. 148—1923 for light grade oil.

(ii) Lubricating oil, consisting of a mineral oil with 20 per cent blown rape oil and complying with the following specification—

Specific Gravity at 15.6° C.	0.92 approximately.
Closed Flash Point.	Not less than 188° C.
Viscosity (time of outflow of 50 cm. ³ in Redwood viscometer).	75 sec. at 200° F. (93° C.); 38 sec. at 300° F. (149° C.).
Acidity, calculated as oleic acid.	Not more than 1 per cent.
Loss in 2 hr. at 212° F. (100° C.) (determined as described below).	Not more than 0.3 per cent.

The oil shall be free from mineral acid.

The loss at 212° F. (100° C.) shall be determined by heating 9 grammes of oil in a flat-bottomed porcelain dish approximately 2½ in. diameter and ¾ in. deep.

(b) The test for the effect of oil shall be carried out on a coil of cotton-covered copper wire. The coil employed for the test shall be of circular section, approximately 2 in. internal diameter and 2 in. long. The coil shall be wound with wire 0.036 in. diameter double cotton covered, and the depth of the winding shall be approximately ½ in. Before the application of varnish to the coil, it shall be dried for 6 hours in an oven at a temperature from 95° C. to 100° C. The coil shall then, whilst still hot, be dipped in the varnish under test, and allowed to

remain immersed for a minimum period of 5 to 10 minutes or until such time as all bubbling ceases. It shall then be removed from the varnish, allowed to drain, and placed in a drying oven for 15 hours at a temperature from 95° C. to 100° C., unless the varnish manufacturer recommend a higher temperature. The coil shall then be again dipped for a further period of about 5 minutes, and the drying operation carried out as before.

The effect of oil on the varnish shall be determined by immersing coils in the oils specified in (a). The test shall be carried out as specified in (a), and the effect on the varnish shall be stated, for example, by the formation of sludge on the varnish and by the loss of adhesion between the turns of the coil.

B. Applicable to—

Vulcanized fibre (E.R.A.), varnish paper and varnish fabric products (E.R.A.), varnish cotton cloth (E.R.A.).

Also to pressboard, timbers, moulded compositions, and other insulating materials which are likely to be used in positions where they come in contact with oils.

CONDITIONING

Unless otherwise stated, specimens shall be subjected to *dry* conditioning before the test to determine the effect of oil is carried out.

METHOD OF TEST (BASED ON E.R.A. DIRECTIONS)

Specimens of the material shall be heated in oil in accordance with the directions given in Test No. 11 (Shrinkage Test (b) in Hot Oil), except that the period of immersion shall be 7 days.

After this heat treatment the condition of the specimens with regard to disintegration, warping, splitting, blistering, softening, or other deterioration shall be stated.

TEST No. 25

FREEDOM FROM CHEMICAL REACTION

A. Applicable to—

Varnish paper and varnish fabric products (E.R.A.).

The tests outlined below are also applicable to other fibrous dielectrics, and in particular the tests for acids or alkalis have been applied by the E.R.A. to vulcanized fibre, pressboard, and untreated papers.

CONDITIONING

Tests for freedom from chemical reaction shall be carried out on the material as received, without any special conditioning.

METHOD OF TEST (E.R.A.)

Samples of the material shall be tested for the presence of the following—

Ammonia (particularly applies to synthetic varnish products).

Phenol (particularly applies to synthetic varnish products)

Free mineral acids and alkalis.

Organic acids.

Lime.

Chlorides.

The tests shall be carried out as follows—

(a) *Free Ammonia.* Two grammes of the material^w are pulped with 200 cm.³ of distilled water free from ammonia and boiled for a short time under reflux condensation. The filtrate is distilled until 100 cm.³ have come over, and the distillate is made up to 250 cm.³ Varying aliquot amounts from 5 cm.³ to 100 cm.³ are tested with Nessler's reagent until a suitable coloration is found. This is then matched by means of standard ammonium chloride solution by the usual colorimetric method as employed in water analysis.

(b) *Combined Ammonia.* The distillation residue from the above determination is made up to 200 cm.³ with water free from ammonia. A little caustic soda is added, and the processes of distillation and Nesslerization are repeated as above.

(c) *Phenol.* Ten grammes of material^w are pulped with 200 cm.³ of water, and the whole mixture distilled until about 100 cm.³ have come over.

To the distillate so much dilute iodine solution is added as is needed just to give a faint coloration with starch-paste. Phenol is then determined by the Koppeschaar method, i.e. sodium bromate solution and acid are added, and after tribromophenol has separated out, the unused bromine is titrated back with KI and thiosulphate.

(d) *Acids or Alkalies.* Ten grammes of the material^w are pulped

^w It is important to reduce the material to as finely divided a condition as possible, since fully-stoved synthetic resins cannot be brought into solution except by the most destructive solvents. In some cases, soaking in water and subsequent pounding in a mortar will reduce the material to a pulp in which the synthetic resin is in a sufficiently fine state of division. In more refractory cases it will be necessary to pulverize the material in a laboratory mill. A suitable method is wet grinding in a cone mill, after the material has been cut into the smallest possible pieces.

with 200 cm.³ of distilled water and gently boiled for 1² hour. The

* It has been found that alkali is sometimes difficult to remove from pulp. It is recommended that if, on testing after 1 hr. boiling, alkalinity is indicated, the pulp should be re-boiled with another 200 cm.³ of distilled water, and further boilings given if considered necessary.

cooled liquid is filtered perfectly clear by the aid of a pump. The

filtrate is tested with phenolphthalein.^y If acid, it is titrated with

^y If the solution to be titrated is not coloured, methyl orange has been found reliable.

N/100^z caustic soda; if alkaline, with N/100⁴ hydrochloric acid. Should the filtrate be very dark, alkali blue 6B may be used as indicator. If alkali blue 6B is not available, and phenolphthalein is used, the solution must be suitably diluted with a neutralized diluent, or alcoholic or ethereal extracts must be employed. When a large amount of free acid or alkali^z is found, it is advisable to boil the residue with fresh

^z When a large amount of acid or alkali is present, $\frac{N}{10}$ solution may be used.

water, titrate again, and repeat as requisite.

The acidity or alkalinity shall be expressed as—

Equivalent to — per cent of SO_3 , or

Equivalent to — per cent of NaOH.

(e) *Organic Acids*. Ten grammes of the conditioned sample shall be extracted to exhaustion with 100 cm.³ of methylated spirit in a soxhlet apparatus. The alcoholic extract thus obtained shall be cooled, and to it shall be added 50 cm.³ of benzene and a considerable excess of N/2 sodium hydroxide, e.g. 50 cm.³; the mixture shall be well shaken for about 5 minutes, and then the excess of alkali back titrated with N/2 H_2SO_4 and phenolphthalein.

(f) *Lime and Chlorides*. The lime and chlorides shall be determined by the usual laboratory methods from the ash after the incineration of the material.

B. Applicable to—

Untreated textile fabrics, including cloth, tape, webbings, and yarn (E.R.A.).

CONDITIONING

According to E.R.A. directions for the study of unvarnished textile fabrics, the material should be subjected to no special conditioning before the tests for acidity and alkalinity are carried out.

METHOD OF TEST (E.R.A.)

(a) *Test with Distilled Water*. A sample of fabric 6 in. square shall be boiled in a beaker for 5 minutes in 50 cm.³ of distilled water, the solution then being poured off into a flask, leaving the drained sample in the beaker. A further 50 cm.³ of distilled water shall be added to the sample and boiled for 5 minutes, the solution being poured off into the flask containing the first extract. To the contents of the flask (which need not be cooled) 0.5 cm.³ of 1 per cent phenolphthalein solution shall be added, and the whole titrated with N/100 caustic soda if acidity is indicated, or with N/100 sulphuric acid if alkalinity is

indicated. The number of cm.^3 of $\text{N}/100 \text{ NaOH}$ or of $\text{N}/100 \text{ H}_2\text{SO}_4$ shall be stated.

A blank test shall be carried out on the water and glass vessels used in this test.

(b) *Test with Alcohol.* A sample of fabric 6 in. square shall be boiled in industrial alcohol, complying with British Standard Specification No. 2D. 9, in the same manner as in (a). The procedure for the determination of acid or alkali specified in (a) shall be followed, and the number of cm.^3 of $\text{N}/100 \text{ NaOH}$ or of $\text{N}/100 \text{ H}_2\text{SO}_4$ shall be stated.

A blank test shall be carried out on the industrial alcohol and glass vessels used in this test.

Note.—The glass vessels used for these tests shall be boiled out several times with distilled water before the tests are carried out.

TEST No. 26

AGEING TESTS

A. Applicable to—

Insulating varnishes (E.R.A.)

CONDITIONING

No special conditioning is called for before the tests for determining the ageing properties of a varnish are carried out. The varnish samples employed shall be taken from the bulk according to the directions quoted in Test No. 32.

METHOD OF TEST (E.R.A.)

The ageing test shall be carried out on Japanese Gampi tissue paper, on specimens varnished and dried in accordance with the directions given in Test No. 23.

After removing not less than $\frac{1}{2}$ in. from one edge, six strips, each $\frac{3}{4}$ in. wide, shall be cut parallel to the edge removed.

The strips shall be placed in a uniformly heated oven at a temperature from 100°C. to 105°C. A strip shall be removed at the end of 50, 100, 200, 300, 400, and 500 hours respectively, and shall be tested at room temperature (approximately 20°C.) as specified below. The test shall be made between $\frac{1}{2}$ hour and 1 hour after removal from the oven.

Each strip shall be bent double under a weight of 1 lb. applied on 1 sq. in. The effect on the varnish film at the bend shall be noted. The number of hours that the varnish has been heated when it first cracks in the bending shall be stated.

B. Applicable to—

Insulating papers (E.R.A.).

CONDITIONING

The specimens shall be subjected to *normal* conditioning before the tests for determining the ageing properties of the papers are carried out.

METHOD OF TEST (E.R.A.)

The tendency of the paper to deteriorate with age shall be proved by a comparison of the bursting strength of the paper before and after it has been heated in a drying oven at a temperature of 110° C. for 24 hours.

The bursting strength shall be determined in accordance with the following method—

The paper shall be gripped on to a ring, leaving a free circular membrane, which shall be subjected to fluid pressure until it is broken. The value of the pressure required to break the paper, as shown on an indicator attached to the apparatus, shall be expressed in lb. per sq. in. (or kg. per sq. cm.).

This value is defined as the bursting strength of the paper.

The bursting strength of the paper shall be measured at 10 positions equally spaced diagonally across a test piece 1 ft. long and the foot width of the roll, when the paper is submitted in a roll, and at 10 positions equally spaced diagonally across a sheet when the paper is submitted in sheets.

The maximum, minimum, and mean values of the bursting strength shall be stated.

The direction in which the paper commences to break with respect to the length of the paper shall be noted.

C. Applicable to—

Varnished cotton cloth (E.R.A.), unvarnished textile fabrics (E.R.A.).

A test of this nature may also be applied to other textile fabrics, both treated and untreated, when it is desired to determine the ageing properties.

CONDITIONING

The cloth shall be *normal* conditioned before the test for ascertaining the ageing properties of the material is commenced.

METHOD OF TEST (E.R.A.)

The tendency of the varnished cloth to deteriorate with age shall be determined by the change in the bursting strength after it has been heated at a temperature from 90° C. to 95° C.

The bursting strength measurements shall be carried out as soon as the temperature of the material has fallen to 20° C. The result shall be compared with that obtained after the varnished cloth has been subjected to normal conditioning for one week.

Note.—The E.R.A. directions do not state exactly how the tendency

to age shall be expressed, but it may be suggested that the percentage decrease in the bursting strength of the material, expressed as a percentage on the bursting strength in the *normal* condition, may be taken as a means of expressing the ageing when it is required to quote a figure for comparative purposes.

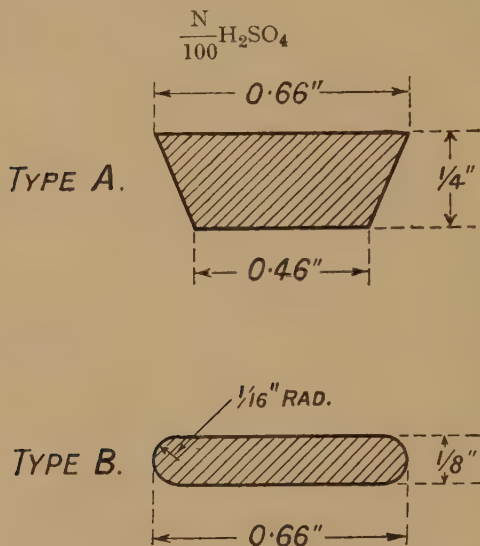


FIG. 66.—Dimensions of Specimen for Ageing Tests.

TEST No. 27

SLOT WEDGE TEST

A. Applicable to—

Vulcanized fibre (E.R.A.).

Also applicable to varnish paper and varnish fabric products, hard woods, and other materials offered as slot wedge materials.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the Slot Wedge Test is carried out.

METHOD OF TEST (E.R.A.)

The specimens shall be machined to one of the dimensions shown in Fig. 66 and shall be inserted in the special jig shown in Fig. 67, representing a machine slot. The specimen shall be forced radially out of the slot in a compression testing machine, and the pressure required per inch of length to displace the wedge shall be determined.

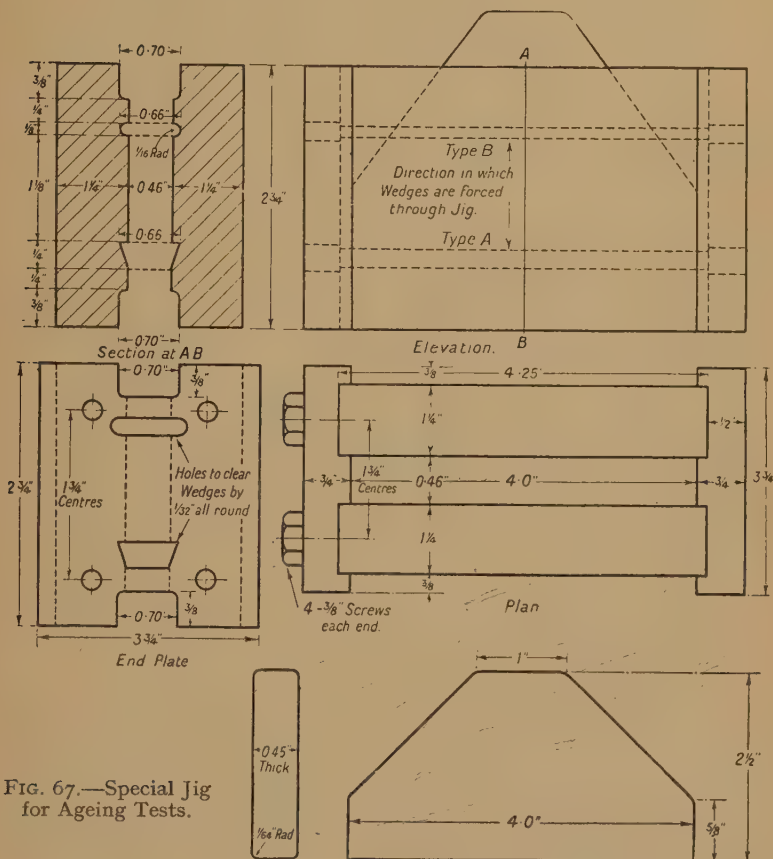
TEST No. 28

FREEDOM FROM CONDUCTING PARTICLES AND
PINHOLES

A. Applicable to—

Untreated papers (E.R.A.), pressboard (E.R.A.).

Vulcanized fibre (leatheroid, etc.) (E.R.A.).

FIG. 67.—Special Jig
for Ageing Tests.

CONDITIONING

For the purpose of this test the specimens need not be subjected to any particular conditioning.

METHODS OF TEST

(a) *Thick Materials* (E.R.A.). In the case of materials thicker than $\frac{1}{16}$ in. a specimen 6 in. by 4 in. shall be photographed by X-rays.

The number of metallic particles and pinholes per square foot shall be stated.

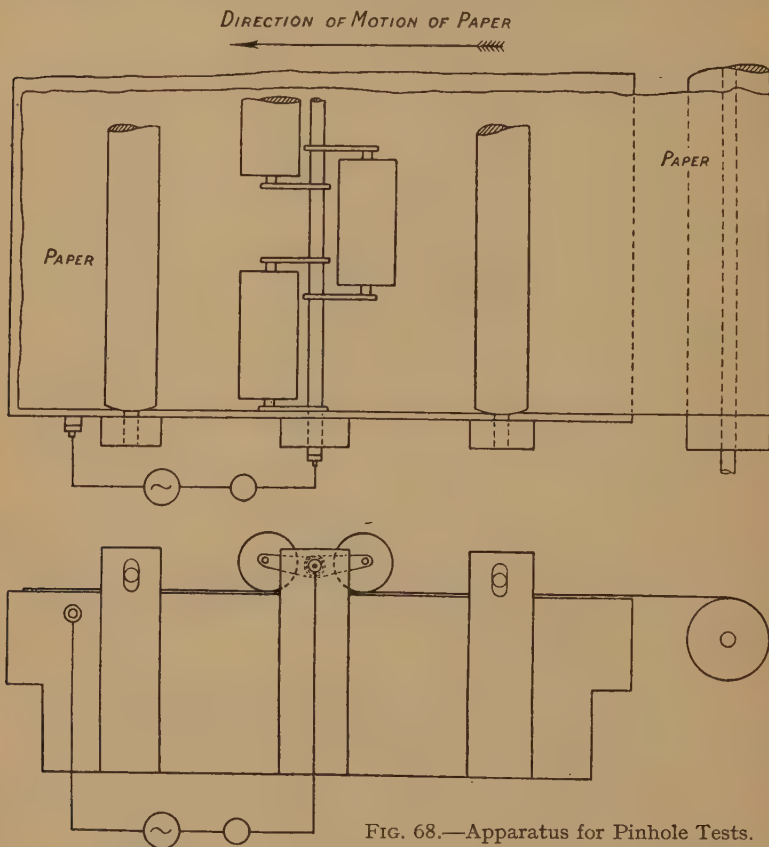


FIG. 68.—Apparatus for Pinhole Tests.

(b) *Thin Materials* (E.R.A.). In the case of materials up to and including $\frac{1}{16}$ in. thick, specimens not less than 12 in. square shall be tested by the following methods—

(i) The specimen shall be saturated with a dilute solution of hydrochloric¹ acid, specific gravity approximately 1.1, and then immersed

¹ The hydrochloric acid in test (i) has a tendency to act upon the iron oxides present, thus producing considerable discoloration of the specimen. Test (i) does not really disclose the presence of copper and brass particles.

Test (ii) detects iron, copper, and brass particles, but it is not sufficiently penetrating especially when testing a dark specimen, and metallic particles well inside the samples may not be disclosed. Also, after a short time the discoloration extends throughout the specimen, thus causing difficulty in detecting the metallic particles.

Test (iii) does not indicate the metallic oxides.

in a potassium ferrocyanide solution to precipitate the iron present. Each iron particle will produce a blue spot on the paper.

The number of deeply stained particles per square foot of the specimen shall be stated.

(ii) A 1 per cent solution of silver nitrate shall be applied to the surface of the specimen. Each metallic particle will produce a black spot on the specimen.

The number of black spots per square foot of the specimen shall be stated.

(iii) The specimen shall be dipped into a 1 per cent solution (by volume) of acetic acid, and then allowed to air-dry for 1 hour while lying flat on a cloth.

(c) *Materials Supplied in Roll Form, i.e. Papers, Thin Pressboard, Leatheroid, etc.* (E.R.A.). The material shall be drawn at a speed of approximately 2 ft. per minute between a metallic plate and a system of overlapping rollers as shown in Fig. 68.

The rollers shall be of brass, 3 in. long and $\frac{7}{8}$ in. diameter. The edges of the rollers shall be rounded to a radius of $\frac{1}{32}$ in. Each roller shall exert a pressure of approximately 10 oz. on the paper under test.

The paper shall be subjected to an alternating potential difference of 50 volts R.M.S. per mil thickness of the paper. The frequency of the potential difference shall be 50 cycles per second. A resistance shall be inserted in the testing circuit so that the rollers are not damaged when a puncture occurs. An electric lamp or other suitable indicator shall be used to demonstrate failure of the insulation. On failure occurring, the defective spot shall be marked and the paper drawn back and passed through a second time. The ability of the part, originally defective, to pass test on the second application shall be noted.

Not less than 5 sq. ft. of the paper shall be subjected to test.

The number of punctures per square foot shall be stated.

TEST No. 29

TESTS FOR RESINOUS AND NITROGENOUS MATERIALS IN ELECTRICAL INSULATING PAPERS

A. Applicable to—

Electrical insulating papers (E.R.A.).

CONDITIONING

The specimens shall be *normal* conditioned before the tests for determining the presence of resinous and nitrogenous materials are carried out.

METHODS OF TEST

(a) *Test for Resinous Materials* (E.R.A.). The total resinous material shall be determined as follows—

Five grammes of the paper shall be cut into strips about $\frac{1}{2}$ in. wide

and folded into numerous small crosswise folds. The strips shall be placed with 500 cm.³ of acidulated alcohol (450 cm.³ of 95 per cent alcohol, 45 cm.³ of distilled water and 5 cm.³ of glacial acetic acid) in a litre flask fitted with a reflux condenser, and the contents heated on a water bath for not less than 2 hours. The alcohol shall then be poured off, and the paper residue washed with acidulated alcohol twice, the washings being added to the main bulk.

The extract shall be poured into a weighed glass dish and the flask washed out with a small portion of the acidulated alcohol, which is added to the original extract. The alcohol shall then be evaporated, and just before the extracted total resins in the glass evaporating dish go to dryness they shall be cooled, taken up with 25 cm.³ of ether, and transferred to a 250 cm.³ separatory funnel containing 100 cm.³ of distilled water and 25 cm.³ of a saturated solution of sodium chloride, the latter being present to prevent the formation of an emulsion. The funnel shall be shaken thoroughly and the contents allowed to separate. The water shall be drawn off into a second separatory funnel and washed again with 25 cm.³ of ether.

The two ether extracts shall be combined and washed two or three times with 100 cm.³ of distilled water to remove all the salt and foreign matter other than ether-soluble resins. Should glue, which is extracted from the paper by the alcohol, interfere by emulsifying with the ether, it may be removed readily by adding a strong solution of sodium chloride to the combined ether extracts, shaking thoroughly and draining it off, repeating, if necessary, before washing with distilled water. The washed extract shall be transferred to a weighed glass dish, evaporated to dryness slowly, dried in an oven at 95° C. (203° F.) to 100° C. (212° F.) for $\frac{1}{2}$ hour, cooled and weighed. The increase in weight of the dish divided by 5 and multiplied by 100 will give the percentage of the total resinous material.

(b) *Test for Nitrogenous Material (Glue and Casein)* (E.R.A.). The total nitrogenous material shall be determined by the Kjeldahl-Gunning method described in *Atack's Chemists' Year Book*, 1921 edition, page 130, as follows—

About 1 gm. of the paper is cautiously treated in a long necked resistance flask with about 20 c.c. of conc. sulphuric acid (excessive frothing must be avoided). The heating is continued until the frothing subsides and then the flask is allowed to cool. (The nitrogen has been converted into ammonium sulphate.) Ten gm. of potassium sulphate and a crystal of copper sulphate are added and the flask again heated until the contents are of a pale green colour. Cool and dilute with 500 c.c. of distilled water.

One hundred c.c. of 30 per cent caustic soda are carefully poured down the side of the flask, avoiding mixing with the acid. The flask is connected with the acid absorption apparatus, the contents of the flask shaken up, and the liberated ammonia distilled into excess N/10 acid. This is back titrated with N/10 caustic soda and the ammonia titration calculated to nitrogen.

A blank test must be carried out.

If no casein be present the percentage of nitrogen obtained multiplied by 5.6 will give the percentage of glue in the sample of paper.

Note.—This test is of no value for the determination of the percentage of glue when glue and casein are present, since both contain nitrogen.

TEST No. 30

DETERMINATION OF THE PERCENTAGE COMPOSITION OF MICA PRODUCTS

A. Applicable to—

Mica products of all kinds which are built up from mica splittings using an organic bond and with or without organic backing material.

CONDITIONING

The samples shall be conditioned for 1 hour at 100° C. The weight before and after conditioning shall be recorded.

METHOD OF TEST

Note.—The method of test here described is that developed and employed by the Research Department of The Metropolitan-Vickers Electrical Co., Ltd.

Sample. The test sample shall consist of a 2 in. square (4 sq. in.) piece of the material. *Before conditioning* the average thickness of the material shall be determined by micrometer measurements.

Determination of Percentage of Paper. The sample shall be disintegrated by dissolving in alcohol, after which the paper shall be removed and re-treated with fresh alcohol to extract any varnish remaining. The paper shall then be dried and measured to determine its volume. The volume of paper shall then be expressed as a percentage of the total volume of the sample before conditioning.

Note.—Where the paper used is procurable in its untreated state, and its specific gravity may therefore be determined, greater accuracy will result if the volume of the sample after re-drying is determined from its weight, rather than by measurement, since the action of the alcohol tends to cause the paper to swell and may produce an error as much as 3 per cent.

Determination of Percentage of Mica. The mica left after the above-mentioned disintegration of the sample, shall be separated from the solvent by filtering, after which it shall be placed in a weighed crucible and "ashed" in a muffle furnace at a temperature between 500° C. and 600° C. When cool, the crucible and mica shall be again weighed, and the weight of mica thus determined. For the purpose of calculating the percentage of mica by volume, the specific gravity shall be taken as 2.785, and the volume of mica thus calculated shall be expressed as a percentage of the total volume of the sample before conditioning.

Expression of Percentage of Varnish. The percentage of varnish

shall be expressed as the difference between the total volume (taken as 100) and the combined percentage volumes of paper and mica.

In the case of micanite constituted of mica and varnish, without any reinforcement of paper or other material, the disintegration in alcohol may be dispensed with and the sample may be incinerated immediately after conditioning.

TEST No. 31

DETERMINATION OF PERCENTAGE OF INCOMBUSTIBLE MINERAL MATTER PRESENT IN TEXTILE FABRICS AND PAPERS

A. Applicable to—

Unvarnished textile fabrics (E.R.A.), electrical insulating papers (E.R.A.).

CONDITIONING

The specimen shall be dried at a temperature of 105° C. to 110° C. for 3 hours immediately before the test for percentage of mineral ash is carried out.

METHOD OF TEST (E.R.A.)

The E.R.A. directions call for the sample ignited to be "not less than 50 grammes" in the case of textile fabrics, and "about 5 grammes" in the case of insulating papers.

The specimen shall be completely ignited with all precautions against loss. The residue of incombustible matter (mineral ash) shall be weighed, and the amount of the same shall be computed as a percentage of the weight of the dried sample (i.e. after conditioning).

TEST No. 32

DRYING TESTS ON VARNISHES

A. Applicable to—

Insulating varnishes (E.R.A.).

CONDITIONING

The varnish used in this test shall not be subject to any special conditioning, but shall be freshly drawn from the consignment of material under test, utilizing suitable sampling tubes, and ensuring that the bulk is thoroughly stirred before the sample is withdrawn. The varnish shall not be exposed to the air for more than 5 minutes before the drying test is commenced.

METHODS OF TEST (E.R.A.)

(a) *Drying of Surface Film.* The test shall be carried out on either Japanese Gampi tissue paper approximately 1 mil thick, or on sheet copper or brass about 5 mils thick. The dimensions of the specimen shall be approximately 8 in. long and 6 in. wide.

Preparation of Specimens. The density of the varnish to be employed for the drying test shall be so adjusted by trial with the thinner recommended by the varnish manufacturer that the thickness of the varnish film on each side of the paper or metal sheet shall be not less than 3 mils, and not more than 3.5 mils, in the vicinity of the centre of the specimen.

To obtain the required thickness of film the varnish shall be diluted with the solvent recommended by the varnish manufacturer, and the paper or metal shall be varnished as follows—

To determine the correct density of the varnish, strips of paper or metal shall be dipped in samples of diluted varnish containing amounts of thinner ranging from 5 per cent to 50 per cent (by volume). After draining for 30 minutes at room temperature, approximately 20° C., the specimen shall be dried as specified below. Each specimen shall then be dipped again in varnish of the same density as before, drained for 30 minutes at room temperature, and dried as specified below. During the draining, care shall be taken that the specimens remain stationary. When being dipped, drained, and dried the second time the specimens shall be suspended in the opposite direction to that employed for the first film. The depth of the varnish in which the specimen is dipped shall be about $\frac{3}{4}$ in., and the specimen shall be immersed completely for approximately 1 minute, care being taken to remove all froth. The specimen shall be drawn through the varnish at the same rate as the excess of varnish slips from the surface of the specimen.

Note.—If none of the specimens is of the specified thickness, the required density of the varnish may be obtained by interpolation.

Method of Drying. Six specimens coated with air-drying varnish shall be dried in free air at a temperature from 20° C. to 25° C.

Six specimens shall be dipped in baking varnish as specified above and allowed to drain for 30 minutes at room temperature, approximately 20° C., and then dried in an oven heated externally at a temperature from 95° C. to 100° C., unless the varnish manufacturer recommends a higher temperature. The air content of the oven shall be changed completely not less than three times per hour. After the first coat has been dried the specimens shall be removed from the oven and allowed to cool to air temperature, approximately 20° C.; they shall then be dipped a second time and drained and dried as before. When being dipped, drained, and dried the second time, the specimens shall be suspended in the opposite direction to that employed for the first film.

The first specimen shall be tested as specified below, 30 minutes before the expiration of the time stated by the varnish manufacturer, and thereafter further specimens shall be tested similarly at intervals of 10 minutes.

Time of Drying. The varnish shall be considered dry when a circular piece of No. 4 Whatman filter paper $1\frac{3}{8}$ in. diameter does not adhere to the varnish when it is pressed on the surface of the varnish for

1 minute by a cylindrical weight of 1 lb., 1 in. in diameter. The filter paper shall be applied in the vicinity of the centre of the specimen. The test shall be carried out at a temperature from 15° C. to 25° C.

(b) *Drying Throughout a Mass of Winding.* The test to determine the drying property of a varnish throughout a mass of winding shall be carried out on coils of double cotton-covered copper wire. The coil employed for the test shall be of circular section, approximately 2 in. internal diameter and 2 in. long. The coil shall be wound with wire 0.036 in. diameter, double cotton covered, and the depth of the winding shall be approximately $\frac{1}{2}$ in.

The time required for the varnish to dry satisfactorily shall be determined as follows—

Several specimen coils shall be provided which shall be thoroughly dried in a hot vacuum oven and immediately immersed for 10 minutes in a bath of the varnish at the density recommended by the manufacturer, or other trial density. After draining, the coils shall be baked at different temperatures and for different periods of time, the varnish maker's recommendations being taken as an initial guide. When cold, the coils shall be sawn through and the several layers and turns separated. The baking conditions necessary to obtain effective adhesion between the cotton-covered wires throughout the mass of the winding shall be recorded.

TEST No. 33

INTERNAL RESISTANCE

A. Applicable to—

Varnish paper and varnish fabric (E.R.A.).

Also applicable to other laminated products in which the electrical resistance in the direction parallel to the laminae is likely to vary from that measured in Test No. 34, which is made in a direction perpendicular to the laminae.

CONDITIONING

The specimens shall be conditioned according to the directions quoted in Test No. 34 (Volume Resistivity).

METHOD OF TEST

Two holes shall be drilled (perpendicularly to the laminae) to a depth equal to two-thirds the thickness of the board. The diameter of the holes shall be 5 mm., and the distance between their centres shall be 15 mm. The holes shall be filled with mercury, and the resistance between them shall be measured at the end of each minute over a period of 10 minutes electrification at a potential difference of 500 volts.

The resistance shall be expressed in megohms, and a curve shall be plotted showing the relationship between resistance and time.

In reporting the results of tests the thickness of the specimen shall be stated in every case.

TEST No. 34

VOLUME RESISTIVITY TEST

A. Applicable to—

Vulcanized fibre (E.R.A.), varnish paper and varnish fabric products (E.R.A.).

Also applicable to pressboard, moulded compositions, micanite products, natural and artificial slates, and similar materials when supplied in either board or tube form.

Note.—The E.R.A. has evolved the special method of test described in *B* below for determining the volume resistivity of hard composite dielectrics, so that, in accordance with their rules, moulded compositions should strictly be subjected to the tests described in *B*. It is suggested, however, that they can more easily be tested in most cases by using the standard apparatus designed for testing vulcanized fibre, etc., which does not require the preparation of an accurately machined specimen.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before volume resistivity tests are carried out. In the case of hard rubber (ebonite, etc.), and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resin and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.), and as Class D non-ignitable boards.

METHODS OF TEST

(a) *Boards* (E.R.A.). A specimen 4 in. square shall be set up for test as shown in Figs. 69 and 70. The resistance shall be measured at the end of each minute over a period of 10 minutes electrification at a potential difference of 500 volts. The resistivity shall be expressed in megohms per centimetre cube, and a curve shall be plotted showing the relationship between resistivity and time.

(b) *Tubes* (E.R.A.).

Note.—As the E.R.A. directions lay down no dimensions for the specimen to be used in this test, it is suggested that the length of tube should be at least 3 in. longer than the length covered by the tinfoil electrode of standard area, i.e. 1,963 sq. mm.

After closing one end the tube shall be filled with mercury and

tinfoil shall be bound on the outside of the tube with 10 mil binding wire, closely wound over the whole length of the tinfoil. The area of the tinfoil shall be equal to that of the inner electrode used in the

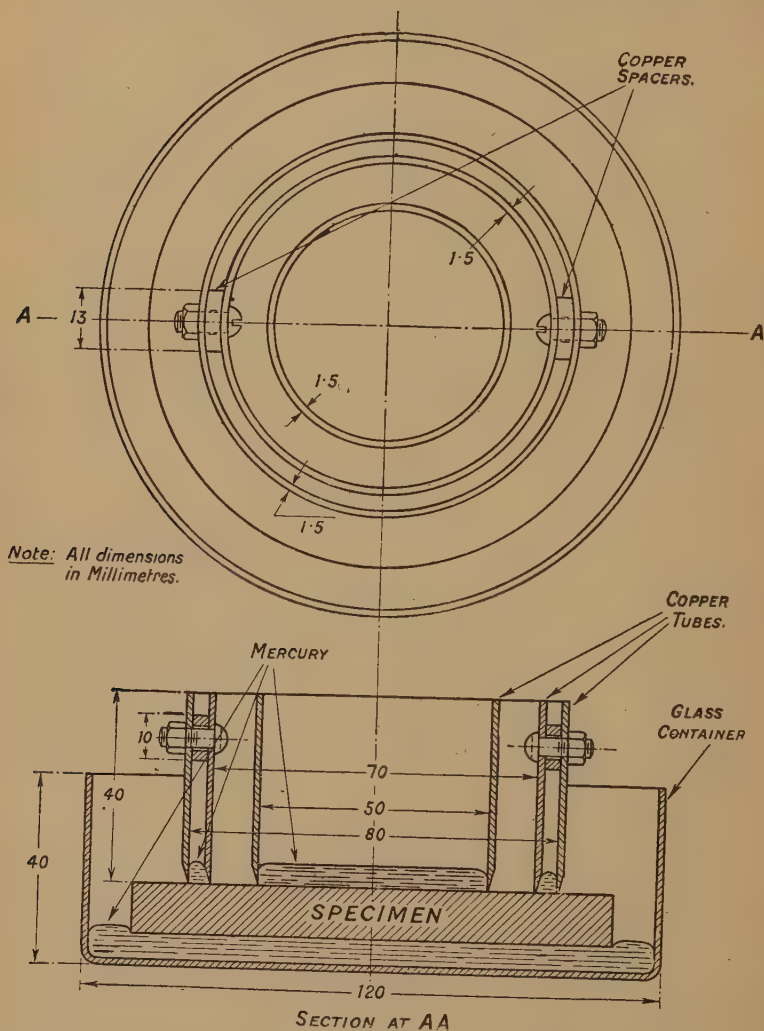


FIG. 69.—Arrangement of Specimen for Volume Resistivity Test.

resistivity of a sheet, i.e. in (a) above. A guard ring of wire shall be bound round the tube on each side of the tinfoil. The resistance shall be measured at the end of each minute over a period of 10 minutes

electrification at a potential difference of 500 volts. The resistivity shall be expressed in megohms per centimetre cube, and a curve shall be plotted showing the relationship between volume resistivity and time.

In calculating the volume resistivity in the case of a tube the following formula may be made use of—

$$\rho = \frac{2\pi RL}{\log_e \frac{r_2}{r_1}}$$

where

L = length of tinfoil in centimetres.

r_1 = inner radius of tube in centimetres.

r_2 = outer radius of tube in centimetres.

R = measured resistance in megohms.

ρ = volume resistivity in megohms per centimetre cube.

TESTS UNDER SPECIAL CONDITIONS

In addition to the tests above described, which are required to be carried out with the specimen in dry condition, the following special conditions have been laid down by the E.R.A. to meet a demand for tests at a higher temperature and at a high relative humidity.

Test at High Temperature. After the specimen has been heated for 24 hours at a temperature from 105° C. to 110° C., the resistance is measured at the high temperature. The electrodes shall be raised to the high temperature before the resistance is measured.

Test Cold at High Relative Humidity. After the specimen has been subjected to a controlled atmosphere, relative humidity not less than 95 per cent at a temperature from 15° C. to 25° C. for 18 to 24 hours, the resistance is measured whilst the specimen is in the controlled atmosphere.

Test at Tropical Humidity. After the specimen has been subjected to a controlled atmosphere, relative humidity not less than 90 per cent at a temperature from 45° C. to 50° C. for 18 to 24 hours, the resistance is measured whilst the specimen is in the controlled atmosphere. The electrodes shall be raised to the temperature stated before the resistance is measured.

B. Applicable to—

Hard composite dielectrics (E.R.A.).

Note.—The introduction to the E.R.A. directions defines hard composite dielectrics as comprising vulcanized rubber, vulcanized materials other than rubber, and unvulcanized materials, whether moulded to final shape or in forms such as board (sheet), rod, or tube from which parts may be machined.

CONDITIONING

The E.R.A. directions (Technical Publication B/S1) show nine conditions in which hard composite dielectrics may be tested, but as

these conditions do not fall in line with the more recently published E.R.A. conditioning directions for dielectrics in general, it is not proposed to quote them here.

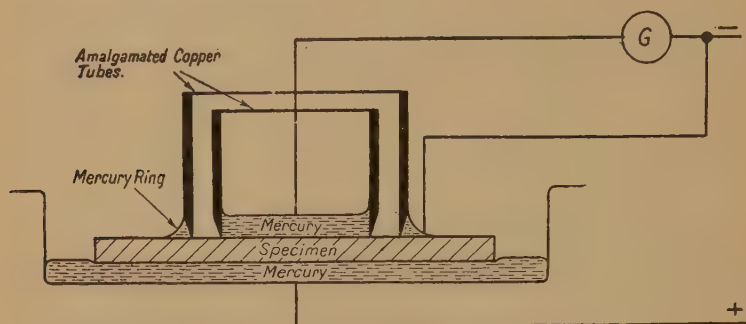


FIG. 70.—Diagrammatic Arrangement of Apparatus for Volume Resistivity Test.

METHOD OF TEST

Mouldings, Boards, Rods, and Tubes. The methods of carrying out the tests and of expressing the resistivity laid down by the E.R.A. in

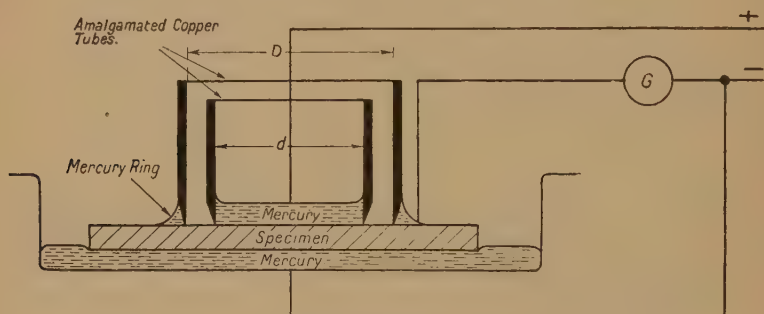


FIG. 71.—Apparatus for Surface Resistivity Test.

Technical Publication B/S1 are substantially the same as those quoted above in (a). The forms of specimens, however, differ widely from those laid down in (a), and are therefore shown in Figs. 72 and 73.

TEST No. 35

SURFACE RESISTIVITY TEST

A. Applicable to—

Vulcanized fibre (E.R.A.), varnish paper and varnish fabric products (E.R.A.).

Also applicable to pressboard, moulded compositions, micanite products, natural and artificial slates, and similar materials when supplied in either board or tube form.

Note.—The E.R.A. has developed the special method of test described in *B* below for determining the surface resistivity of hard

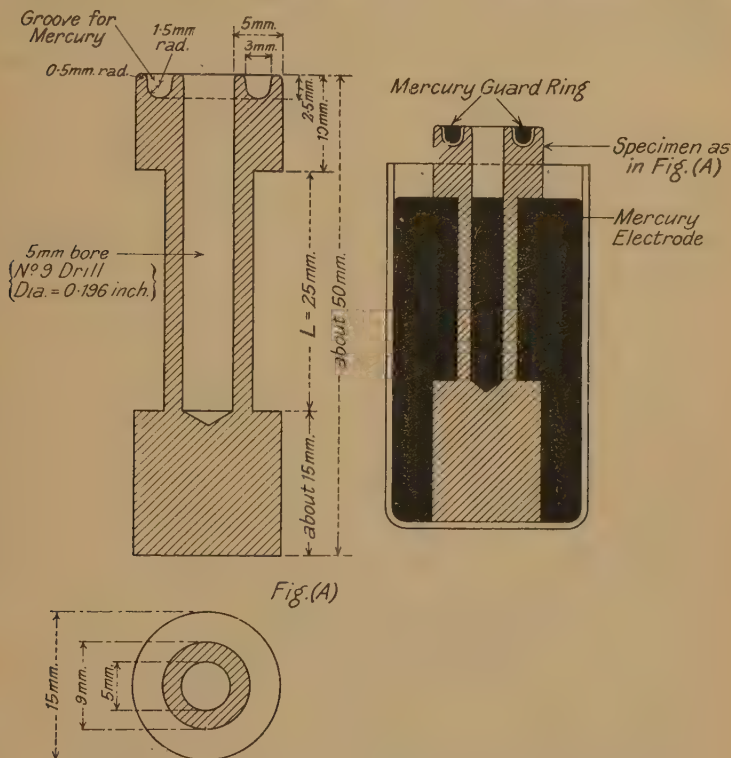


FIG. 72.—Showing Form and Arrangement of Specimen Prepared from Rod.

composite dielectrics so that, in accordance with their rules, moulded compositions should, strictly speaking, be subjected to the tests described in *B*. It is suggested, however, that they can more easily be tested in most cases by using the standard apparatus designed for testing vulcanized fibre, etc., which does not require the preparation of an accurately machined specimen.

CONDITIONING

Unless otherwise specified, specimens shall be subjected to *dry* conditioning before the surface resistivity tests are carried out. In

the case of hard rubber (ebonite, etc.), and of Class D non-ignitable boards, the temperature of conditioning should be reduced to 40° C. to 45° C. In the case of certain varnish paper products made with natural resins and gum bonds (E.R.A., Class II, Grade B), and also made with asphaltum bonds, the temperature of conditioning should be reduced to 55° C. to 60° C.

Moulded compositions containing rubber and bitumen shall be regarded in the same category as hard rubber (ebonite, etc.), and as Class D non-ignitable boards.

METHOD OF TEST

(a) *Boards* (E.R.A.). The specimen employed shall be exactly similar to that used in determining the volume resistivity, and shall be set up for test as shown in Fig. 71. The surface resistance shall be measured at the end of each minute over a period of 10 minutes electrification at a potential difference of 500 volts. The surface resistivity shall be expressed in megohms per centimetre square, and a curve shall be plotted showing the relationship between surface resistivity and time.

(b) *Tubes* (E.R.A.). The surface resistance of a tube (or rod) shall be measured between two 10 mil wires bound tightly round the tube 1 cm. apart. The tube shall be filled with mercury to act as a "guard ring."

The surface resistance shall be measured at the end of each minute over a period of 10 minutes' electrification at a potential difference of 500 volts. The surface resistivity shall be expressed in megohms per centimetre square, and a curve shall be plotted showing the relationship between surface resistivity and time.

Note.—In calculating the surface resistivity of a standard specimen of sheet (board) material the following formula may be made use of—

$$\delta = \frac{R_s \times 2\pi}{\text{Log}_e \frac{D}{d}}$$

where D and d have the significance indicated in Fig. 71 :

R_s The surface resistance in megohms.

δ The surface resistivity in megohms per centimetre square.

TESTS UNDER SPECIAL CONDITIONS

In addition to the tests described above, which are required to be carried out with the specimen in *dry* condition, the E.R.A. directions for the study of varnish paper and varnish fabric products call for tests to be made where possible in the *normal*, *damp*, *tropical*, and *recovered* conditions.

The E.R.A. directions for the study of vulcanized fibre call for the tests to be made with the material in the *normal* condition.

B. Applicable to—

Hard composite dielectrics (E.R.A.).

Note.—The E.R.A. directions for the study of hard composite dielectrics define the same as comprising vulcanized rubber, vulcanized materials other than rubber and unvulcanized materials, whether moulded to final shape or in forms such as board (sheet), rod, or tube from which parts may be machined.

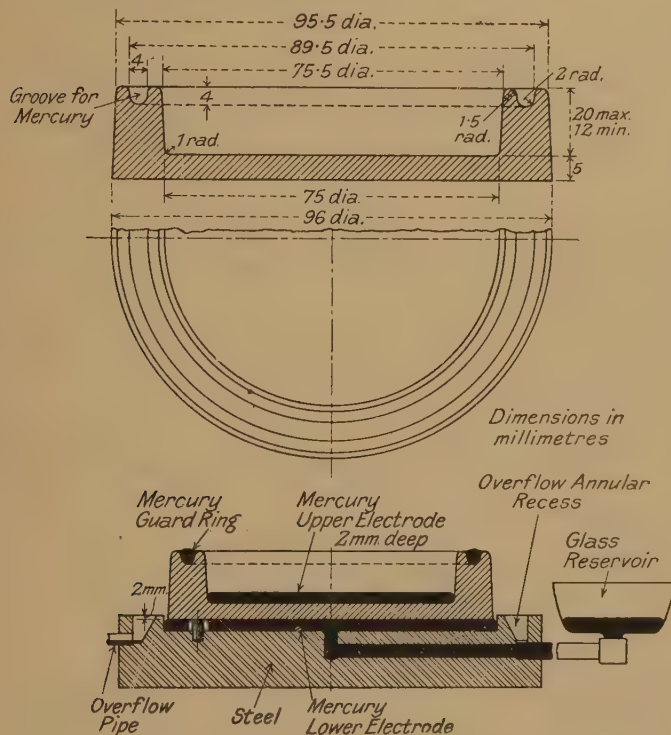


FIG. 73.—Showing Method and Arrangement of a Specimen.

CONDITIONING

The E.R.A. directions (Technical Publication B/S1) show six conditions in which hard composite dielectrics may be tested, but as these conditions do not fall in line with the more recently published E.R.A. conditioning directions for dielectrics in general, it is not proposed to quote them here.

METHOD OF TEST

Mouldings, Boards (Sheets), Rods, and Tubes. The methods of carrying out the tests and of expressing the surface resistivity laid down by the E.R.A. in Technical Publication B/S1, are substantially the same as those quoted above in (a). The forms of the specimens

and of the electrodes, however, differ widely from those laid down in (a) above, and are therefore shown in Figs. 72 and 73.

TESTS ON INSULATING OILS

Applicable to—

Insulating oils for use in transformers, oil switches, and circuit breakers (B.E.S.A.).

*Reprinted from British Engineering Standards Association,
Specification No. 148—1923*

SAMPLING

The method consists in withdrawing and transferring a sample of oil from the bottom of the container to a sample carrier or bottle by means of a sampling tube or "thief" under the conditions mentioned below.

SAMPLING APPARATUS

The *sampling bottles* should be preferably stoppered glass bottles, 1 quart size.

The *sampling tubes* or "thiefs" should be thick glass tubes of about $\frac{1}{4}$ in. (6 mm.) inside diameter at the bottom, ground slightly oblique, and of length sufficient to touch easily the bottom of the oil barrel or drum. Tubes of the following dimensions are frequently employed—

Length	22 in. (559 mm.).
Internal diameter	$1\frac{1}{4}$ in. (32 mm.), constricted at both ends.
Diameter of inlet and outlet.	$\frac{1}{4}$ in. (6 mm.).

They are made of thick glass tubing and have two handles fused on to the side near the top of the tube.

Sampling bottles and sampling tubes must be scrupulously clean and dry. When not in use they should be kept in a hot, dry cabinet, free from dust, the bottles being unstoppered and the sampling tubes held vertically in a rack.

PREPARATION FOR SAMPLING

Samples shall not be drawn from containers out of doors, and not from containers indoors when the oil is cooler than the surrounding air, on account of the risk of moisture condensation.

The containers should be arranged with their bungs uppermost and should rest undisturbed for at least 24 hours before the sample is taken, in order that any contained moisture may have an opportunity to settle. Before any container is opened, the part around the bung must be thoroughly dried and cleaned.

The sampling bottle should have its stopper inserted before removal from the cabinet, and should not be unstoppered any sooner than is necessary for the purpose of introducing the oil.

METHOD OF TAKING THE SAMPLE

The sampling tube is inserted until it touches the bottom of the container, the upper end of the tube being closed by the thumb. The thumb is then removed, allowing the oil to flow into the bottom of the tube. The upper end of the tube is again closed with the thumb, and the tube now containing oil is withdrawn. The first sample thus taken should be regarded as a washing for the tube and should be thrown away.

The sampling tube is again filled, the same procedure being followed, and the oil withdrawn should be used to wash out the sampling bottle and then thrown away.

The sampling bottle is then filled with oil from the bottom of the container by means of the sampling tube, in accordance with the foregoing procedure, and immediately stoppered and labelled for identification and tests.

Immediately after sampling, the bung should be replaced in the container and tightened.

The sampling bottle may be filled by samples taken from each of several containers representing one single consignment, when it is the intention to take one average sample. In this case, one sampling tube may be used for the entire filling of the sampling bottle.

When separate test samples are being taken, a separate sampling tube must be employed with each sampling bottle, or the sampling tube previously used must be thoroughly washed with oil and the washings thrown away before commencing to take the new sample.

The lower end of the sampling tube must not be touched by the hand during the sampling process, nor must it be brought in contact with cotton waste or rag, nor allowed to touch any dirty surface.

CLEANING SAMPLING APPARATUS

All sampling tubes and sampling bottles should be thoroughly drained and washed with petroleum ether and then with pure dry methylated spirits before being returned to the cabinet in which they are kept. Waste, rag, or other material which can leave fibres on the apparatus must not be employed in cleaning.

TEST No. 36

METHOD OF CARRYING OUT TEST FOR TENDENCY TO
SLUDGE

One hundred c.c. of the oil shall be introduced into a clean, dry, round-bottomed flask, fitted to a glass condenser, by means of a ground-in or other suitable joint. The dimensions of the flask are given in Fig. 74.

A piece of pure sheet copper having a clean, bright, polished surface, and measuring 2 in. by $1\frac{1}{4}$ in. by 0.004 in. thick (51 mm. by 32 mm. by

0.10 mm.) shall be rolled into a cylinder $1\frac{1}{4}$ in. (32 mm.) high, so that the edges shall touch.

The coiled strip shall stand vertically on the bottom of the flask. The whole of the bulb of the flask shall be immersed in an oil bath, care being taken that, when the oil bath reaches 150°C . (302°F .), the ground-in joint shall be above the surface of the oil in order to ensure that no leakage of the latter into the test flask can occur.

The upper portion of the condenser is provided with a one-hole

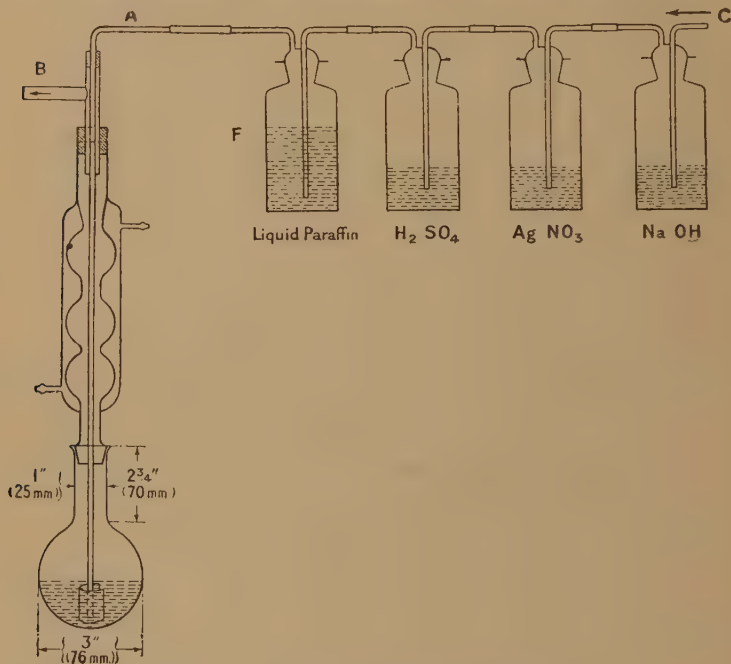


FIG. 74.—Flask for Carrying Out Sludge Test.

rubber bung carrying a glass T-piece (B), which in turn carries the glass air inlet tube (A); the internal diameter of the T-piece (B) shall be 0.4 in. (10 mm.), and the internal diameter of the inlet tube (A) shall be 0.16 in. (4 mm.). The inlet tube (A) shall reach to within $\frac{1}{8}$ in. (3 mm.) of the bottom of the flask, and pass axially through the cylinder of copper. Air pressure shall be applied to the tube (C) so as to cause a current of air to bubble through the oil.

The air, before entering the tube (A), shall be dried and purified by passing it through three wash bottles containing sodium hydrate solution, of specific gravity 1.355, 10 per cent silver nitrate solution, and concentrated sulphuric acid respectively. The inlet tubes of the wash bottles shall dip $\frac{1}{2}$ in. (12.5 mm.) below the surface of the reagents.



FIG. 75.—Oil Sludge Test Apparatus developed by Metropolitan-Vickers Electrical Co., Manchester.

The rate at which air is bubbled through the oil shall be indicated by means of a tell-tale bottle (*F*) inserted between the sulphuric acid wash bottle and the inlet tube (*A*).

The temperature of the oil bath containing the test flask shall be maintained constant at 150° C. (302° F.) for 45 hours, and during the period of heating the current of air shall be adjusted so as to pass through the tell-tale tube at the rate of 0.07 cu. ft. (2 litres) per hour, measured at normal temperature and pressure by means of an accurate gas meter.

After the 45 hours' treatment, the flask shall be removed from the oil bath and allowed to cool to a temperature below 100° C. (212° F.). The contents shall then be transferred to a beaker, diluted with three times their volume of petroleum spirit, and allowed to stand overnight for the sludge to separate. Any deposit remaining in the flask shall be removed by means of suitable solvents or mechanically, if necessary, and added to the sludge in the beaker.

The petroleum spirit used shall be free from aromatic hydrocarbons and have a specific gravity of 0.70 to 0.72 at 15.5° C. (60° F.). Not less than 75 per cent by volume shall distil over at a temperature below 110° C. (230° F.), and the final boiling point shall not exceed 150° C. (302° F.).

The liquid shall then be decanted through a filter paper, and the deposit washed on to the filter paper by means of petroleum spirit. The deposit on the filter paper shall then be thoroughly washed with petroleum spirit until free from oil and dried at 100° C. (212° F.) and dissolved as described below.

In the event of the deposit being large, the bulk of it shall be detached from the filter paper, crushed, and re-dried at 100° C. (212° F.) and then weighed. Any traces of deposit which adhere to the paper shall be removed by means of hot benzene (C_6H_6) or other suitable solvents. The solvent is then evaporated off on a water bath and the residue weighed.

The result is expressed as a percentage, thus—

$$\text{Percentage of sludge} = \frac{\text{weight of deposit in grammes}}{\text{specific gravity of the oil}}$$

TEST No. 37

METHOD OF TEST FOR LOSS BY EVAPORATION

This test shall be carried out by either the rotating oven or the toluene vapour bath method, as follows—

(a) *Rotating Oven.* The rotating oven may be driven by clockwork or by an electric motor, and may be gas or electrically heated. The apparatus as shown in Figs. 76 and 77 is recommended. In Fig. 76 the apparatus is shown closed for running, whilst in Fig. 77 it is shown open with the cage (*c*) removed to show how the beakers are arranged. The cage (*c*) works inside an iron casing (*a*) with holes at the side, and

provided with a removable lid (*b*) having a chimney at the top to permit of gentle ventilation, produced by the heat and slow movement of the cage; therefore no trouble from draughts of air can arise. The cage (*c*) accommodates 12 beakers, which shall be $3\frac{1}{4}$ in. to $3\frac{1}{2}$ in. (83 mm. to 89 mm.) in depth, $1\frac{1}{2}$ in. to $1\frac{5}{8}$ in. (38 mm. to 41 mm.) in diameter at the top, and $1\frac{3}{8}$ in. (35 mm.) in diameter at the bottom.

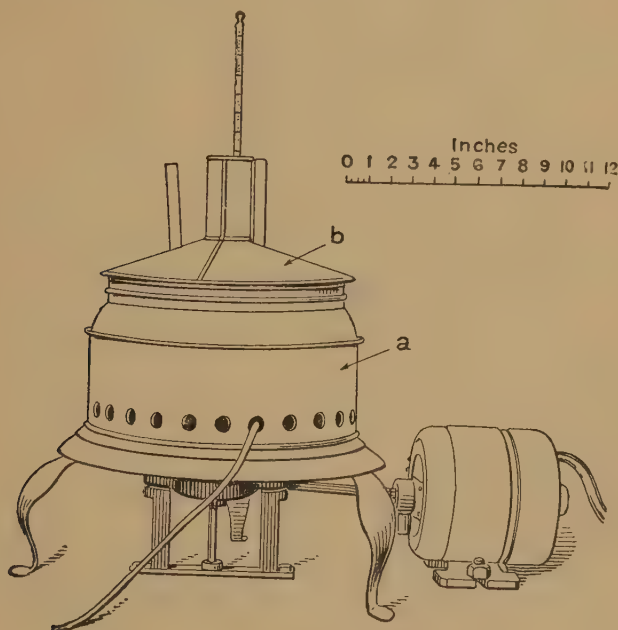


FIG. 76.—Apparatus for Evaporation Tests.

The heating unit is situated in the side of the casing in the plane of the holes. It rests on insulation which lies on a sheet of steel forming the bottom of the casing, and above it, and between it and the revolving cage, is a false bottom which fits the casing very loosely and thus equalizes the temperature by preventing local convection currents rising from the heating unit.

Two grammes of oil shall be weighed into each beaker. This produces a layer of oil of roughly $\frac{1}{8}$ in. (3 mm.) depth and having an exposed area of about 1.8 sq. in. (11.6 sq. cm.). The height of the beaker relative to the depth of oil prevents loss by "creeping" of the oil up the sides and reduces to a minimum any effect of air currents in the oven.

The drive shall be such as to give a speed of rotation of from 4 to 8 r.p.m. .

The result shall be given in terms of loss of oil by weight, expressed as a percentage of the original quantity.

(b) *Toluene Vapour Bath*. The apparatus used is illustrated in Fig. 78, which is almost self-explanatory. The apparatus consists of

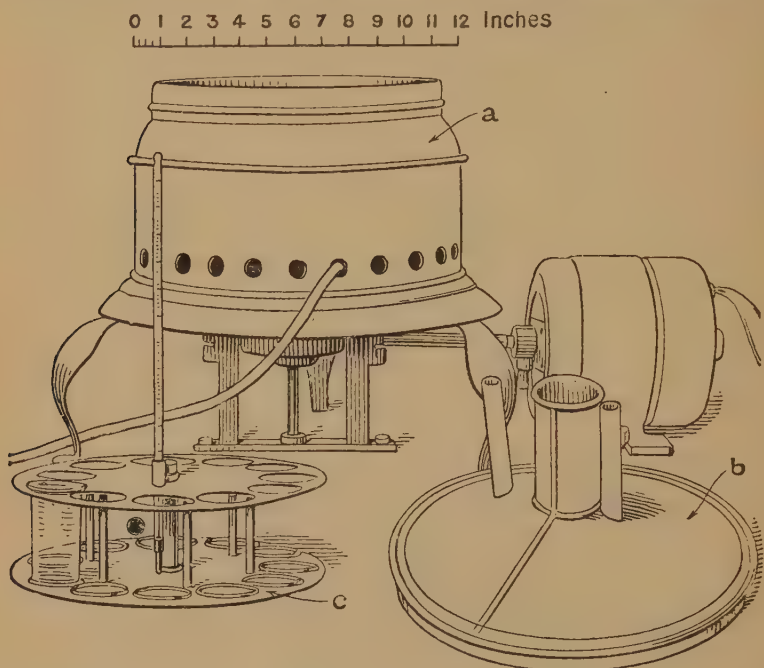


FIG. 77.—Apparatus for Evaporation Tests.

a vapour bath constructed of $\frac{1}{32}$ in. (approximately 0.8 mm.) sheet copper. The trough running longitudinally down the bath is 13 in. long by $1\frac{5}{8}$ in. deep by $2\frac{3}{8}$ in. wide (330 mm. by 41 mm. by 60 mm.), and the (D) shaped portion forms a jacket surrounding the trough. Two holes, 1 in. (25 mm.) and $\frac{3}{4}$ in. (19 mm.) in diameter respectively, on opposite sides of the trough and at opposite ends of the vapour jacket, are fitted with tubes projecting to a height of 1 in. (25 mm.) above the surface of the lid, and are intended to carry a short condenser and a thermometer to prevent the loss of toluene and to control the production of the vapour.

The trough shall be filled with lead shot (0.064 in. (1.6 mm.) diameter) and the interior of the boiler or vapour jacket about half filled with commercially refined toluene. The whole bath is set up on a wrought iron stand having legs of 10 in. (254 mm.) length, and the toluene boiled by means of gas jets placed under the bath.

The boiling point of toluene at ordinary atmospheric pressure is

110° C. (230° F.), but the loss of heat in transmission makes the temperature of the oil under test only 100° C. (212° F.). The temperature of the oil should be checked by embedding one or more thermometers in the shot, or, if preferred, by putting a "blank" test in, with the thermometer placed in the oil.

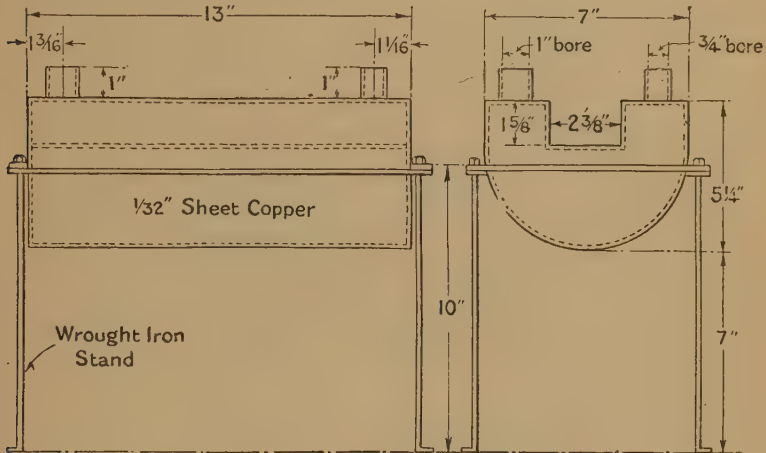


FIG. 78.—Toluene Vapour Bath.

To avoid variation due to draughts of air passing over the beakers containing the tests, a movable screen 6 in. deep by 12 in. by 7 in. (152 mm. by 305 mm. by 178 mm.) should be provided and placed on the bath so as to surround the beakers. The use of a vapour-heated trough ensures a steady and definite temperature and avoids complex heat-regulating apparatus.

Into each weighed beaker of glass, quartz, or porcelain of $1\frac{1}{2}$ in. (38 mm.) in diameter by $1\frac{1}{2}$ in. (38 mm.) in depth, shall be placed 5 c.c. (roughly 4.8 g.) of the oil, and the total weight determined by re-weighing.

Each beaker shall then be embedded right up to its lip in the lead shot in the trough and heated for 8 hours.

When cold, the beaker shall be re-weighed. With beakers of the above dimensions, the surface area of oil exposed is about 1.8 sq. in. (11.6 sq. cm.).

The result shall be given in terms of loss of oil by weight expressed as a percentage of the original quantity.

TEST No. 38

METHOD OF TEST FOR FLASH POINT

The test shall be made with either the Pensky-Marten or Gray's apparatus. These are very similar in principle, and the method for

using them is identical, the only material difference being in the stirring gear. Generally the former apparatus is preferred. (See Fig. 79.)

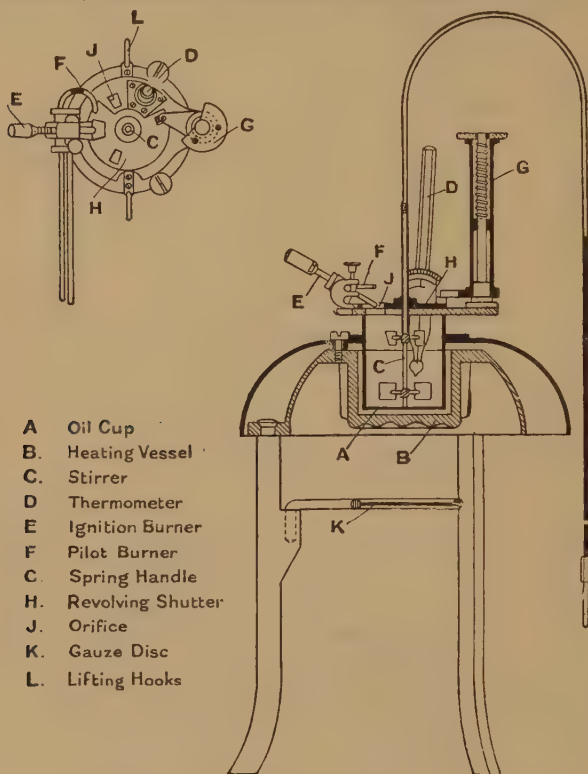


FIG. 79.—Pensky-Marten Flash-point Apparatus.

The cover of the oil cup (*A*) consists of two parts, the portion joined to the rim and an upper portion (*H*) which revolves through a small arc. In each portion there are three orifices, (*J*), the central one, being twice the area of the two lateral ones. These orifices may be made to coincide, or the openings may be completely closed, according to the relative positions of the two portions of the cover. The lower part of the cover is fitted with a vertical rod serving as a support to a tube. This tube can be rotated upon the rod by turning the non-conducting milled head (*G*), at the upper end, and the action compresses a spring. At the lower end the tube is provided with an arm which, by the action of the spring, is held against a vertical stud. A pin projecting downwards from the arm engages with a slot in the revolving portion of the cover (*H*), and on turning the milled head the openings in the upper portion of the cover are brought over those in the lower

portion. At the same time a flange projecting from the edge of the revolving portion of the cover (*H*) comes into contact with the oscillating gas jet (*E*), and this is depressed so that at the same moment when the central openings coincide the gas jet is brought to the orifice (*J*).

On releasing the pressure requisite to turn the milled head (*G*), the openings in the cover are again closed by the action of the spring, and the gas jet (*E*) is brought back to the horizontal position. The gas jet is provided with a screw valve, by means of which the size of the flame can be adjusted. The gas is supplied through a lateral tube forming one of the supports on which the jet oscillates, the other support consisting of a small stud. A pilot gas jet (*F*) is fixed at right angles to the ignition burner (*E*), to re-ignite the burner if it be extinguished when depressed. The pilot gas jet (*F*) is attached to a tube fixed parallel to the lateral tube supplying gas to the ignition burner (*E*).

In the lower part of the cover of the cup there is a socket for a thermometer (*D*), and in the centre of the cover there is a tube through which the stem of the stirrer (*C*) passes. The stirrer is provided with a pair of paddles working in the oil, and a smaller pair in the vapour space above the oil. It is revolved by means of a flexible wire. The oil cup (*A*) is furnished with a pair of hooks (*L*) for convenience in removing it from the bath, when hot, by means of a forked holder. The heating vessel (*B*) consists of a cast-iron air bath (*B*), with an annular chamber exposed to the flame, and a brass jacket, which serves to check radiation. The jacket is separated from the iron casting by a considerable space at the sides, and by a distance of $\frac{1}{4}$ in. (6 mm.) at the top. The oil cup (*A*) rests upon a jacket, and therefore does not come into contact with the cast-iron. Beneath the bath there is a disc of wire gauze (*K*), which is fitted to a swinging arm, so that it may be turned aside and the flame of a burner allowed to impinge upon the bath when a high temperature is required.

The oil to be tested shall be placed in the oil cup *A*, and the level of the oil shall coincide with the mark inside the cup. The cover, with thermometer in position, shall be placed on the cup and heating commenced. The rate of heating shall be such as to allow the oil to be increased in temperature at the rate of about 4° C. (7° F.) per minute when rhythmically stirred. When the temperature has reached at least 50° C. (90° F.) below the temperature at which the oil flashes, the ignition burner (*E*), which has a flame about $\frac{1}{8}$ in. (3 mm.) in length, shall be depressed slowly into the cup, and then repeatedly every 12 seconds until the oil flashes. Stirring shall cease when the jet is being depressed.

The presence of water in the oil militates against concordant results.

When the apparatus is cleaned with petroleum spirit or the like, care should be taken to drive off the last trace by heating in a well-ventilated oven at 120° C. (248° F.). The same precaution shall be taken in preparing vessels used for the reception of samples prior to test.

Samples used for flash-point determination should not be used subsequently for other tests.

The above test gives the "flash point" of the sample; that is, it determines the temperature to which the oil must be heated under the specified conditions for sufficient vapour to be evolved for the application of a flame to cause a "flash" or momentary ignition of the vapour. This effect is transient, but, if the oil be heated to a higher temperature, the vapour evolved will burn continuously on the application of a flame. The temperature of the oil at which this takes place may be termed the "burning point"; heating the oil to a still higher temperature will cause it to ignite spontaneously without the application of an external flame. These two temperatures do not lend themselves to accurate experimental determination owing to their close dependence upon the conditions under which the operation is carried out, and therefore it is considered inexpedient to include these tests in this specification.

TEST No. 39

METHOD OF TEST FOR VISCOSITY

The test shall be carried out in a Redwood Viscometer as follows—

The viscometer consists of a silvered copper oil cylinder (*A*), about 1 $\frac{7}{8}$ in. (48 mm.) in diameter by about 3 $\frac{1}{2}$ in. (89 mm.) in length, furnished with an agate jet (*J*).¹ (See Fig. 80.) The exterior of the agate jet (*J*) and its metal seating are made slightly conical, and the jet having once been fixed in position, no dislodgment nor leakage can occur, even when the apparatus is used at high temperatures. The copper bath (*C*), which surrounds the oil cylinder (*A*) and into which the oil cup screws, is of such a depth that the level of the bath liquid can be made to coincide with the level inside the oil cylinder (*A*) without any danger of overflow or splashing into the oil cylinder (*A*). A copper tube (*E*), closed at one end, projecting at an angle of 45° from the side of the bath, near the bottom, provides a means of heating the bath liquid, and by the use of a revolving stirrer (*H*) and (*K*), the heating liquid rising from the copper tube can be uniformly distributed through the bath. The stirrer, which carries a thermometer to indicate the temperature of the bath, is so constructed that splashing is prevented. The oil cylinder is furnished with a valve (*V*) consisting of a small brass sphere attached to a wire, the sphere resting in a hemispherical cavity in the agate jet (*J*). A short standard (*R*) attached to the oil cylinder carries a clip (*S*) to support a thermometer in the oil. Inside the oil cylinder, and at a short distance from the top, is fixed a small bracket (*B*) terminating in an up-turned point. To compensate for any slight deviations from the standard bore of the agate jet (*J*), corrections are

¹ Details of jet may be added when the results of the work of the Committee of the Institution of Petroleum Technologists are available.

made by a slight adjustment of the position of the bracket (*B*). This is done before the instrument is sold.

The instrument is supported on a tripod provided with levelling screws. A circular spirit level is provided to fit on the top of the oil cylinder (*A*).

The bath is filled with a suitable liquid to a height approximately

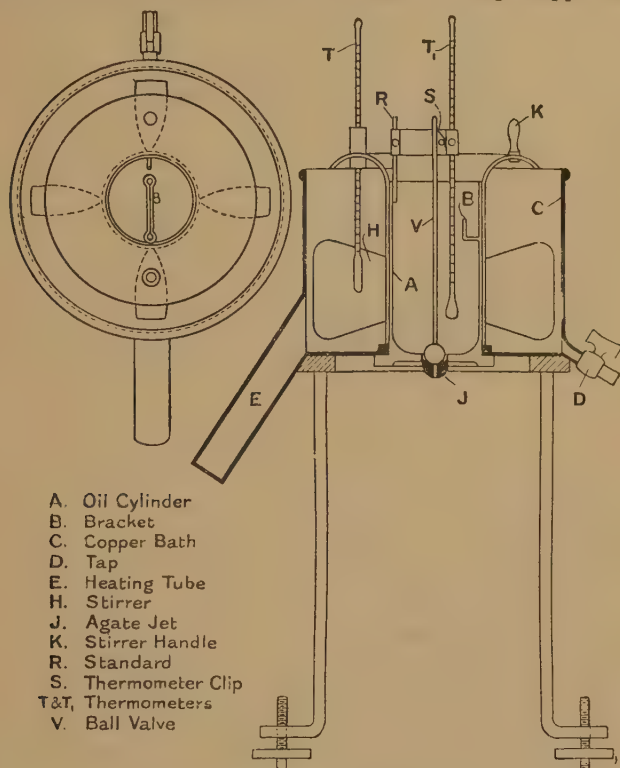


FIG. 80.—The Redwood Viscometer.

corresponding with the gauge in the oil cylinder. Water may be used for temperatures up to 95°C . (203°F .), and mineral oil of high flash point for higher temperatures. The oil to be tested is placed in the oil cylinder (*A*), its height being adjusted to the point of the bracket (*B*), and its temperature adjusted to that at which the determination is to be made, by regulating the temperature of the liquid in the bath to such as will maintain the desired temperature of the oil in the cylinder; the temperature of the bath may have to be several degrees above or below the temperature of the oil being tested, according to

conditions. The oil in the cylinder is stirred by moving the thermometer backwards and forwards until the required temperature is attained, care being taken to avoid the formation of air bubbles. The bath liquid should be kept well stirred. Efficient stirring is the secret of rapid determinations. When the temperature has become constant, allow the oil to remain undisturbed for a short period, to free itself from turbulence; fix the thermometer; adjust the oil to the point of the gauge, and then simultaneously lift the valve and start a stop-watch, and note the time for the efflux of exactly 50 c.c.

For determinations of the viscosity at temperatures above atmospheric, the graduated flask shall be surrounded by a thick layer of cotton wool contained in a beaker, the neck and graduation mark being left exposed to view.

Great care must be exercised in cleaning the instrument, especially the agate jet (*J*).

The viscosity shall be expressed as the time in seconds required for the outflow of 50 c.c. of the sample.

Accurately calibrated thermometers shall be used for the test.

Tests shall be made in duplicate and shall not be accepted if they show a difference exceeding 2.0 per cent. The mean of two tests shall be taken.

TEST No. 40

METHOD OF TEST FOR SOLIDIFICATION VALUE (COLD TEST)

The following method shall be employed for determining approximately the temperature at which an oil ceases to flow—

A refrigerator consisting of a flat-bottomed cylindrical leaden jar, 6 in. (152 mm.) in diameter, 14 in. (356 mm.) in depth, contained in a wooden box measuring 12 in. (305 mm.) square inside and 20 in. (508 mm.) deep, made of wood about $\frac{3}{4}$ in. (19 mm.) thick, shall be used. The space between the jar and the box shall be filled with granulated cork with 3 in. (76 mm.) of cotton waste below the jar. To hold the cork in position and enable the leaden jar to be removed from the box, a cylinder of galvanized sheet steel shall be placed in the centre of the box into which the leaden jar fits. The cylinder is open at the bottom and rests upon the bottom of the box. It shall be held in position by perforated wooden partitions at top and bottom. The waste shall be placed inside it, and the cork around it. The jar shall be covered by a loose wooden lid so placed as to leave about 3 in. (76 mm.) of air space above it. The box may have a hinged lid. The oils to be tested shall be poured to a depth of about 2 in. (51 mm.) into stout-walled glass tubes, 6 in. (152 mm.) long by $\frac{3}{4}$ in. (19 mm.) internal diameter, and the tubes corked.

A similar test tube containing a mineral lubricating oil of medium viscosity and very low setting point shall be used to contain the thermometer, which shall pass through the cork of the test tube and have its bulb immersed in the oil. About 6 in. (152 mm.) of crushed

ice shall be placed in the leaden jar, and the tubes of oil shall be immersed in the ice and left there for at least 1 hour.

They shall then be removed one by one and examined, and any oils which will not flow when the tube is held horizontally and lightly tapped shall be reported as setting in ice (0°C.).

The remainder shall be returned to the ice and the latter mixed with successive portions of powdered salt to lower the temperature by 2° to 3°C. (3.6° to 5.4°F.): 20 minutes' exposure shall be allowed at each decrement of temperature, and the oils examined after each period to see which have set. In this way the setting point may be ascertained to within 3°C. , or closer, if desired, by conducting a second experiment in which the temperature is more gradually lowered when nearing the setting point first found.

By the use of various saline freezing solutions, temperatures down to -24°C. (-11°F.) can be obtained.

In some cases it is desirable to make the test in glass bottles, measuring outside $1\frac{3}{4}$ in. (44 mm.) in diameter and $4\frac{1}{2}$ in. (114 mm.) high to the shoulder, the bottles being filled to a depth of 2 in. (51 mm.) with the oil. In these wider vessels the behaviour of the oil at low temperatures can be more closely observed.

TEST No. 41

METHOD OF TEST FOR DISRUPTIVE STRENGTH

Before sampling, the barrel or other vessel shall stand for 24 hours with the bung or other opening at the top, and the samples shall be drawn from the bottom and thoroughly shaken before testing.

The containing vessel and the electrodes shall be made absolutely clean and dry before the test is carried out. It is found advantageous to carry out the final operation of removal of dust and fibres electrically as follows—

The containing vessel should be filled with oil, and about half the test voltage applied to the electrodes for half a minute to attract dust and fibres. The electrodes should then be washed by pouring fresh oil over them, and the oil in the containing vessel poured away. This operation should be carried out four times, after which the container thus cleaned may be used for 20 consecutive tests without further cleaning. Suitable apparatus is shown in Fig. 81.

The electrodes shall be spheres of steel, brass, or phosphor bronze $\frac{1}{2}$ in. (12.7 mm.) in diameter arranged horizontally¹ with a separation

¹ AUTHOR'S NOTE.—Special tests carried out by the Metropolitan-Vickers Electrical Co. have shown that the horizontal or vertical arrangement of electrodes has little, if any, effect on the results of disruptive strength tests on insulating oils. (See *M.V. Gazette*, November, 1923). It is at present under discussion by the B.E.S.A. to add a note to Clause 8 of Specification 148 to the effect that while vertical or horizontal arrangement of electrodes has been observed to have some effect in tests on very poor oils, the effect is negligible for tests on oils of the quality covered by this specification.

of 0.15 in. (3.81 mm.). (Accurately made balls of steel and phosphor bronze are obtainable from makers of balls for ball bearings). The electrodes shall be immersed in the oil to a distance of not less than 2 in. (51 mm.) from the surface. The volume of the oil used for each



FIG. 81.—Standard Spark Gaps for Testing Insulating Oils.

test shall not be less than 150 c.c. The temperature of the oil shall be between 15.5° C. and 20° C. (60° F. and 68° F.).

The test voltage applied shall be alternating of any frequency between 25 and 100 periods per second. It shall be of approximately sine wave form, and during the test the crest value (as would be determined by spark gap, by oscillograph, or by other approved method) shall be not more than 1.42 times the R.M.S. value. The R.M.S. value shall be measured by a suitable voltmeter connected to the high voltage side of the transformer, by a voltmeter used with a suitably calibrated potential transformer, or by a special winding on the testing transformer.

The test shall be commenced at a voltage of about one-third the test voltage, and shall be evenly increased until breakdown as rapidly as is consistent with its value being indicated by the measuring instrument.

Complete breakdown is known by the establishment of an arc.

Preliminary transient sparking which does not develop into an arc may be ignored.

The oil shall be passed if two tests out of three on the same filling show results within the limit fixed.

This Illustration has been submitted by the British Electrical and Allied Industries Research Association and is issued in this form pending acceptance of the apparatus as the Standard Apparatus for determining the Electric Strength of Insulating Oils.

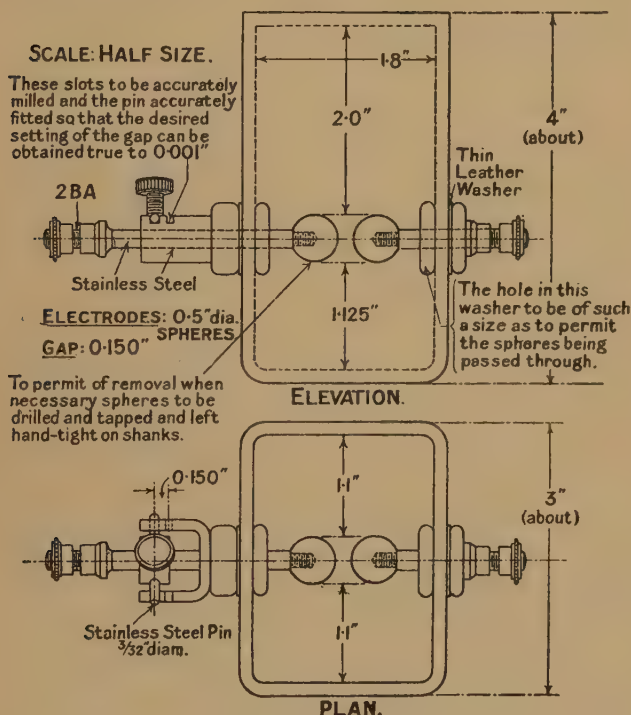


FIG. 82.—Dimensions of Spark Gap Electrodes.

If the electrodes become pitted by the action of the spark they shall be renewed.

The oil used for this test shall not be used for any other tests.

TEST No. 42

MAKING OF TEST FOR ACID VALUE

(a) *Inorganic Acid.* Take 100 g. of the oil and shake with 200 c.c. of warm distilled water, allow time for separation of the oil from the

water and draw off the aqueous portion almost completely; add another 200 c.c. of the water to the oil and again shake and draw off. Mix the two quantities of water which have been drawn off, and, using the mixture, test for the presence of inorganic acids such as hydrochloric, sulphuric, and sulphurous by means of the usual qualitative inorganic tests.

(b) *Organic Acid.* About 25 g. of the oil shall be weighed into a 200 c.c. flask and 50 c.c. of neutral alcohol added. The flask shall be warmed to about 60° C. (140° F.) and the contents titrated with N/100 KOH, using phenolphthalein as indicator, the flask being well agitated during the operation.

TEST No. 43

METHOD OF TEST FOR SAPONIFICATION VALUE

The saponification value, representing the number of milligrammes of potassium hydroxide required completely to saponify the combined and free organic acids contained in 1 g. of the sample, shall be measured as follows—

The following standard solution shall be prepared—

(i) Standard aqueous semi-normal¹ hydrochloric acid, containing 18.25 g. of HCl per litre.

(ii) Standard alcoholic potassium hydroxide containing 40 g. of pure potassium hydroxide (KOH) in 1 litre of pure alcohol.² Allow to stand 1 day and then filter and use the filtered solution.

(iii) A 1 per cent alcoholic solution of phenolphthalein containing 10 g. of the dry indicator per litre of pure neutral alcohol.

The semi-normal hydrochloric acid shall be standardized by means of recently ignited (anhydrous) chemically pure sodium carbonate (Na_2CO_3) and its strength calculated in terms of potassium hydroxide (KOH) per cubic centimetre.

Ten grammes of the sample shall be weighed accurately into each of two clean, dry, 500 c.c. "Resistance" glass flasks.

Into each flask shall be run 25 c.c. of the standard alcoholic potassium hydroxide, which shall be measured off by means of a pipette in such a manner that precisely equal quantities are used.³

These shall form duplicate tests, termed the assay tests.

Into another pair of similar flasks which are empty, but clean and

¹ Since chemically pure hydrochloric acid as usually sold has a specific gravity at 15.5° C. (60° F.) between 1.15 and 1.16, it contains only about 32.0 per cent by weight of real HCl; hence 48.0 c.c. of this acid diluted to 1,000 c.c. yields approximately semi-normal acid.

² It is usual to employ a little water to liquefy the potassium hydrate, but the proportion should not lower the strength of the alcohol below 95 to 96 per cent of alcohol per volume.

³ A good plan is to allow the contents of the pipette to run out rapidly, and drain until two drops have dropped off. The same practice must be used in every test made, also in "blank" tests.

dry, shall be run 25 c.c. of the standard alcoholic potassium hydroxide. These serve for duplicate "blank" tests.

By means of indiarubber bungs there shall be attached to each flask a reflux condenser or a long cooling tube, and the contents of the flask shall be gently boiled on a water bath for 60 to 90 minutes, a rotatory motion being occasionally imparted to the contents to make sure of perfect reaction.

Next the liquid shall be cooled somewhat; there shall be added to each flask 1 c.c. of 1 per cent phenolphthalein solution, and the excess of potassium hydrate remaining unconsumed shall be titrated by means of the standard semi-normal hydrochloric acid solution.

The termination of the titration is shown by the disappearance of the purple colour.

Deduct from the mean of the "assays" the mean of the "blank" tests, and the difference calculated into terms of milligrammes of KOH shall be the saponification value.

TEST No. 44

METHOD OF TEST FOR DELETERIOUS SULPHUR

Twenty-five cubic centimetres of the oil shall be placed in a test tube. A piece of polished copper foil, 1 in. (25 mm.) square, bent into a cylinder, shall be immersed in the oil. The tube and its contents shall be heated in a water bath at 100° C. (212° F.) for 12 hours. Discoloration of the foil shall be taken to indicate the presence of sulphur in a deleterious form.

TEST No. 45

IODINE VALUE

A test of iodine value sometimes gives a valuable indication of sludging characteristics. This test is recommended for general use, and, after further experience has been gained, may be incorporated in a future issue of this specification.

It is considered that the percentage by weight of iodine absorbed by the sample, called the iodine value, as given by the test detailed below should not exceed 2 per cent for Class A oil, or 10 per cent for Class B oil.

SOLUTIONS REQUIRED

For the test the following standard solutions should be carefully prepared—

1. Standard alcoholic solution of iodine. Dissolve 25 g. of chemically pure dry iodine in 500 c.c. of pure 95 per cent alcohol.

2. Standard alcoholic solution of mercury bichloride. Dissolve 30 g. of chemically pure dry mercury bichloride in 500 c.c. of pure 95 per cent alcohol (filtering the latter solution if necessary).

3. Standard aqueous solution of sodium thiosulphate (hyposulphite).

Dissolve 24 g. of the dry and clean crystallized salt in 1,000 c.c. of distilled water.

4. Standard 10 per cent aqueous potassium iodide. Dissolve 100 g. of specially pure potassium iodide in 1,000 c.c. of distilled water. The potassium iodide used must be free from iodates.

5. One per cent starch indicator solution. Prepare afresh each day by boiling pure starch with distilled water. Cool completely prior to use.

6. Chloroform, for solvent purposes. This must be pure and free from acidity.

7. Standard aqueous potassium bichromate solution. Prepare by accurately weighing into a standard litre flask 3.866 g. of pure dry powdered potassium bichromate, adding distilled water to the standard mark and shaking until all is dissolved.

Note.—Keep the "stocks" of iodine solution No. 1 and mercury bichloride solution No. 2 separate.

8. Iodine solution. Prepare the following mixture of solutions No. 1 and No. 2 at least 12 hours prior to test, and do not use it after it has been mixed more than 24 hours.

Mix 1 volume of iodine solution No. 1 with 1 volume of mercury solution No. 2, and allow to stand 12 hours in the dark prior to use.

By duplicate titrations, standardize the sodium thiosulphate solution No. 3 in terms of iodine

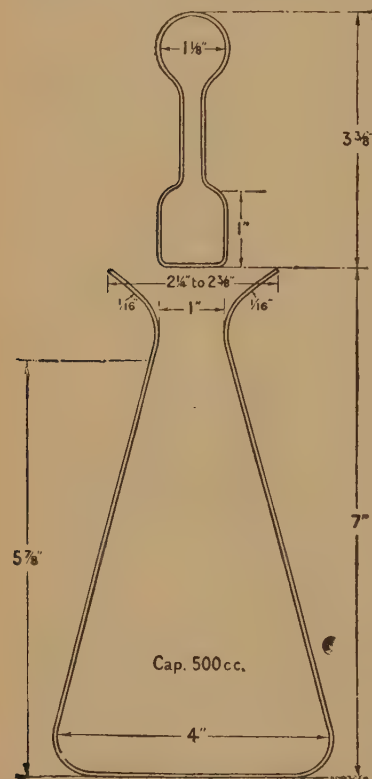


FIG. 83.—"Iodine" Flask.

per cubic centimetre by means of the potassium bichromate solution No. 7, using 1 : 1 hydrochloric acid, the potassium iodide solution No. 3 and starch solution No. 5.

The reaction involved is—

$\text{Cr}_2\text{O}_7\text{K}_2 + 14\text{HCl} + 6\text{KI} = \text{Cr}_2\text{Cl}_6 + 8\text{KCl} + 7\text{H}_2\text{O} + 3\text{I}_2$, the iodine liberated being promptly titrated with the standard solution No. 3.

The atomic weights used are—

O = 16, H = 1.008, Cr = 52.0, I = 126.92, K = 39.10, Cl = 35.46.

Into each of two clean, dry, well-stoppered "iodine" flasks of the form shown in Fig. 83 weigh out accurately 1.0 to 1.25 g. of the sample to be tested.

Add to each sample 10 c.c. chloroform (6), exactly 50 c.c. of the iodine solution (8); mix, stopper and seal the flasks with 1 to 2 c.c. of KI solution (4). These form duplicate "assays."

Place in the dark for not less than 18 hours nor for more than 24 hours, at a temperature not exceeding 20° C. (68° F.).

Prepare two "blanks" (omitting the sample) in the same manner and at the same time.

Upon completion of the absorption period take one flask at a time and treat each as follows—

Pour a little cold water and 1 c.c. of the potassium iodide solution (4) into the "cup" round the stopper. Gently lift the stopper so that this liquid washes down any iodine on the stopper and neck of the flask.

Add 300 c.c. of cold distilled water, 25 c.c. of potassium iodide solution No. 4; mix, and titrate with the standard thiosulphate solution No. 3, using standard starch solution No. 5 for indicator.

Deduct the individual results for the "assays" from the mean of the "blanks" and calculate the difference into grammes of iodine (using the factor found by standardization).

This gives the weight of iodine "absorbed" by each assay.

Multiplying this by 100 and dividing by the weight of oil used for the test gives the "iodine value."

TESTS ON INSULATING CEMENTS

TEST No. 46

Up to the present there are no standard tests on insulating cements. The following series of tests are, however, suggested by the author as being applicable—being for the most part methods which have already been standardized for testing similar products. As the methods of carrying out these tests are not here described in detail, the individual tests have not been given separate test numbers, but the whole group of tests on cements is given one number, i.e. Test No. 46.

(a) SETTING TIME

This test shall be carried out as specified in the B.E.S.A. Specification for Portland Cement (1920), Clause 12.

(b) TENSILE STRENGTH

This test, when required, shall be carried out as specified in the B.E.S.A. Specification for Portland Cement (1920), Clause 10, with the exception that the portion dealing with the keeping of the briquettes

in a damp atmosphere (lines 12 to 19 inclusive) shall be omitted. The briquettes shall be allowed to dry in a normal atmosphere and broken after 2 days, 7 days, and 28 days.

(c) EXPANSION TEST

This test shall be carried out with the standard Chatelier apparatus, as specified by B.E.S.A., and the mould shall be filled as specified in Clause 13, B.E.S.A. Specification (lines 10 to 18 inclusive). The distance separating the indicator points shall then be measured, and the mould allowed to dry in a normal atmosphere. The distance separating the indicator points shall be measured 2 days, 7 days, and 28 days after filling the mould.

(d) SPECIFIC GRAVITY

This shall be obtained by the usual methods.

(e) EFFECT OF TRANSFORMER OIL

A specimen shall be made up as used for Test (a), and shall be allowed to dry for not less than 48 hours. The specimen shall then be completely immersed in transformer oil (B.E.S.A. Specification No. 148), which shall then be raised to a temperature of 90° C. and kept at that temperature for seven days.

(f) EFFECT OF ACID

A specimen as used in Test (e) shall be completely immersed in a solution of H_2SO_4 at a specific gravity 1.25 for 24 hours. The temperature of the liquid to be kept at 40° C.

(g) EFFECT OF ALKALI

A specimen as used in Test (e) shall be completely immersed in a 5 per cent solution of NaOH for 24 hours. The temperature of the solution to be kept at 100° C.

(h) CORROSION TEST

The cement under test shall be used to cement glass test tubes into holes drilled in mild steel, and the specimen shall be examined at intervals of 1 week up to 4 weeks, and after that at intervals of 4 weeks to 6 months. The test tubes used shall be $\frac{1}{2}$ in. external diameter by $2\frac{1}{2}$ in. long, and the steel shall be mild steel $1\frac{1}{4}$ in. by 1 in. Each cement shall be used to cement four tubes into holes $\frac{7}{8}$ in. diameter drilled 3 in. apart completely through the shorter dimension of the bar. The specimen shall be kept in a standard damp atmosphere, i.e. 100 per cent humidity at 25° C.

(i) POROSITY TEST

A specimen as used in Test (e) shall be moulded with a hemispherical cup $\frac{3}{8}$ in. diameter in the centre of one surface, and allowed to dry for

at least 48 hours. The cup shall then be filled with standard solution Eosin dye (as specified for porcelain test) and allowed to remain for 24 hours. The remaining dye shall then be poured off and the specimen broken.

Note.—The cement shall in all cases be mixed to the specification and the consistency which will be used in actual operations.

APPENDIX II

Note.—In this Appendix the numbers given to the figures, tables, and appendices are those assigned by the E.R.A. They do not, therefore, follow the numbering used in the earlier part of the book.

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(E.R.A. Ref. No. L/S2)

TENTATIVE DIRECTIONS FOR THE DETERMINATION OF THE ELECTRIC STRENGTH OF SOLID DIELECTRICS

PART I

RESEARCH TESTS ON ELECTRIC STRENGTH

THE following methods for the determination of the electric strength are recommended when the characteristics of the material are not known, and when a thorough investigation is required to ascertain the electric strength of the material under probable service conditions.

I. GENERAL

It is of primary importance in the case of insulating materials that the recognized electric strength be that of the material when hot and under long continued stress.

It is desirable to test materials at temperatures appreciably above their intended working temperature.

2. FORMS IN WHICH THE MATERIAL MAY BE TESTED

The directions given in this document for the study of electric strength of dielectrics provide for the specimens being in one of the following forms¹—

- (a) Flat sheets and boards.
- (b) Small tubes.
- (c) Large tubes.
- (d) Insulation built up on conductors.
- (e) Moulded compositions.

3. PREPARATION OF MATERIAL PREVIOUS TO TEST

The ability of a material to withstand a damp atmosphere may be due to—

- (a) The material itself being non-absorptive.

¹ Methods of tests for compounds normally solid at room temperature, but liquid when hot, are under consideration.

(b) Additional protection given by a surface layer either developed during manufacture or added subsequently.

In the latter case the specimens shall be prepared for test in the following manner—

(i) When the specimen is in the final form in which it will be used commercially, the protective surface layers of (b) above shall be retained.

(ii) When determining the properties of the material itself it is necessary to exclude the additional protection afforded by the natural layer, by making tests upon sections cut from the material having the surface layers removed at all points.

The results should state in each case how the specimen had been prepared for test.

4. CONDITIONING THE MATERIAL PREVIOUS TO TEST

As the electric strength of most insulating materials is largely influenced by their moisture content, it is desirable that the characteristic curves referred to later should be obtained for as many as possible of the conditions indicated for the class of dielectric under investigation. (See E.R.A. Ref. L/S2, Appendix I.)

When a specimen is moved to an atmosphere of different relative humidity or different temperature, change of moisture content may take place very rapidly. It is, therefore, essential that the electric strength test should be made as soon as possible after the specimen has been removed from the conditioning chamber.

When it is necessary to curtail the number of tests, preference should be given to those which will give the lowest electric strength with due regard to the purposes for which the material may be used. In such cases the abridged tests given in Part II should be employed.

5. METHOD OF HEATING OR COOLING THE SPECIMEN AFTER CONDITIONING AND PREVIOUS TO CARRYING OUT THE ELECTRIC STRENGTH TEST

(a) *Tests in Air.* When it is desired to carry out the electric strength test at a different temperature from that at which the specimen has been conditioned, the following method shall be employed.

Previous to the removal of the specimen from the conditioning chamber the test chamber and two blocks of hard brass each 3 in. diameter by 1 in. thick shall be brought to the temperature at which it is desired to determine the electric strength, also the top electrode specified in Clause 13.

The specimen shall be rapidly transferred from the conditioning chamber to the test chamber, where it shall be immediately placed between the brass blocks for the period stated in E.R.A. Ref. L/S2, Appendix II.

At the expiration of this period the upper brass block shall be removed and the top electrode specified in Clause 13 substituted. The

bottom brass block shall be retained as the bottom electrode, and the electric stress applied as soon as possible after changing the top block.

After conditioning, the specimen must not be exposed, except momentarily, to either the air of the laboratory or the air of the test chamber, as this may largely eliminate the effect of the conditioning.

(b) *Tests in Oil.* When the test is made in oil the latter may retard change of moisture content of the specimen during the time its temperature is being brought to that required for the electric strength test. In this case, therefore, the electric strength is not so liable to be influenced by the period which elapses between the removal of the specimen from the conditioning chamber and the application of electric stress. Previous to the removal of the specimen from the conditioning chamber, the electrodes specified in Clause 13 and the oil bath shall be brought to the temperature at which it is desired to determine the electric strength. When removed from the conditioning chamber, the specimen shall be placed immediately between the electrodes and immersed in the oil bath. Electric stress shall be applied after the period specified in E.R.A., Ref. L/S2, Appendix II.

6. TESTS IN AIR OR OIL

It is often more convenient to immerse the sample under oil whilst the electric strength test is carried out. Under certain conditions the breakdown voltage obtained when the material is tested in oil is not the same as the breakdown voltage which would be obtained if the material were tested in air.

Unless the material is intended for use in oil-immersed apparatus, tests under oil are not permitted if, during the immersion under test conditions, the oil is liable to change the properties of the material in any way.

When testing materials which are intended for use in air and also in oil-immersed apparatus, it is desirable that the effect of conditioning in a damp atmosphere (E.R.A., Ref. L/S2, Appendix I) should be ascertained both in air and in oil.

A schedule suggesting the mode of test which might be used for various classes of the more commonly employed insulating materials is given in E.R.A., Ref. L/S2, Appendix III.

7. METHOD OF EXPRESSING ELECTRIC STRENGTH

A single value for the electric strength of most materials is misleading unless the condition of the material, the thickness, the time of application of the voltage, and the temperature are either stated or clearly indicated.

Values obtained on a rapidly applied test are usually very high, being out of all proportion to the electric strength obtained by the sustained conditions of practice.

The electric strength shall be given in the form of a series of curves in which the actual breakdown voltage, R.M.S. value (0.707 of the

maximum value), is plotted against time and temperature, as shown in Figs. 1 and 2 respectively, and in volts per mil against thickness, as shown in Fig. 3.

In calculating the electric strength in volts per mil, the mean voltage gradient shall be employed, i.e. the breakdown voltage divided by the



FIG. 1.—Time-voltage Curves at Various Temperatures.

thickness of the dielectric. If, in the case of tubes or special shapes, it is desired to calculate the electric strength from the highest voltage gradient, the method given in E.R.A., Ref. L/S2, Appendix IV, may be employed.

When a spark-gap or other method for determining the peak value is used, the peak value shall be given and also the equivalent R.M.S. value, i.e. 0.707 of the peak value. (See Clause 12 (d).)

8. TIME-VOLTAGE TESTS

(a) In carrying out electric strength tests it is important to obtain time-voltage curves,¹ Fig. 1 showing the breakdown voltage over the

¹ Details of an abridged method for the determination of time-voltage curves are given in Clause 19.

time range from 0.5 minute to the time¹ required for the breakdown voltage to become approximately independent of the time.

(b) In special cases, transient voltage tests may be desirable.²

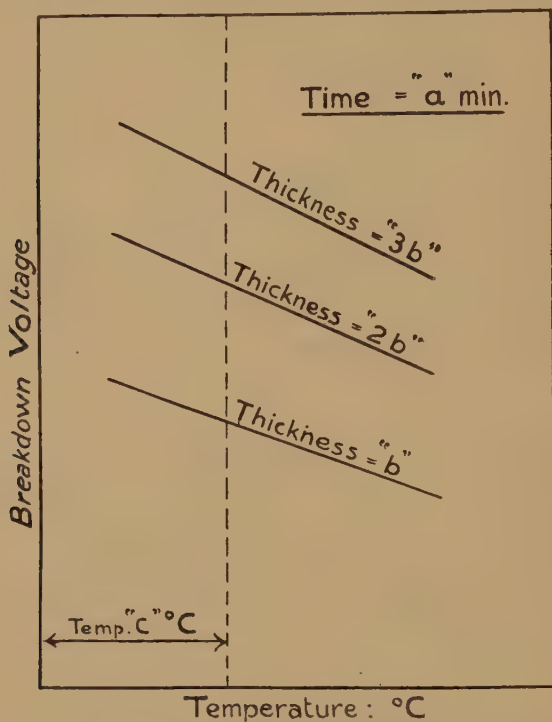


FIG. 2.—Temperature-voltage Curves for Various Thicknesses.

Note.—The temperature-voltage characteristic is not always a straight line.

9. TEMPERATURE-VOLTAGE TESTS

It is desirable that time-voltage tests (see Fig. 1) should be carried out at the temperatures indicated in E.R.A., Ref. L/S2, Appendix III, for the class of material under investigation.

For 1 minute and a selected number of other time values on the time-voltage curves, a temperature-voltage curve should be drawn similar to Fig. 2.

¹ When some dielectrics, such as the commonly used fibrous materials, are tested hot, the time required for the breakdown to become sufficiently independent of the time of application of the voltage may be about 10 min. When, however, the tests are carried out at air temperature (about 20° C.), the time may be considerably longer.

² Methods for carrying out transient voltage tests are under consideration.

10. THICKNESS-VOLTAGE TESTS

When the material is supplied in more than one thickness it is further desirable that sufficient of the foregoing temperature-voltage curves, Fig. 2, should be obtained to enable the thickness-voltage curve to be plotted for definite time and temperature conditions, as in Fig. 3.

One of the thickness-voltage curves should be plotted from the

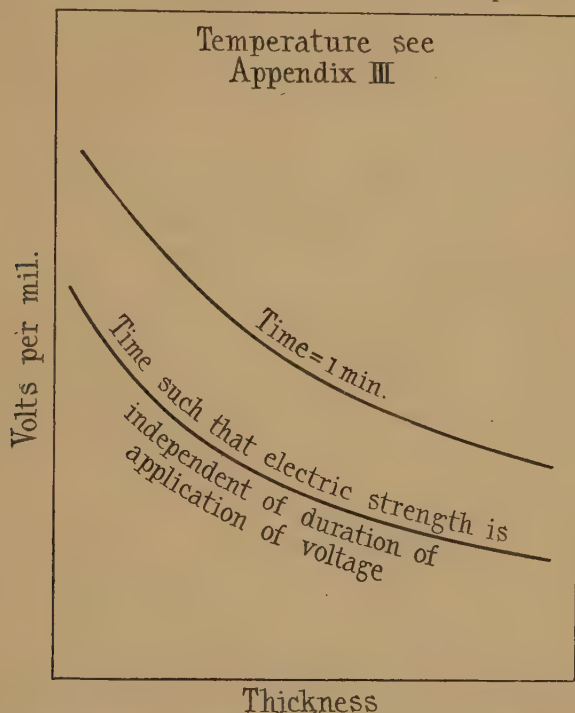


FIG. 3.—Curves Showing Variation of Electric Strength with Thickness.

1 minute values and another from the values obtained when the breakdown voltage is sufficiently independent of the time during which the voltage is applied. (See curves in Fig. 3.)

When it is desired to limit the study of these curves to one temperature, the temperature to be employed shall be the one indicated in E.R.A., Ref. L/S2, Appendix III, for the material under investigation.

To minimize the work required for the construction of a thickness-voltage curve, the number of thicknesses tested may be reduced to three. Two thicknesses are not sufficient, as a knowledge of the shape of the curve is important.

Note.—In plotting thickness-voltage curves the values on the vertical axis should be in terms of volts per mil, and not in terms of breakdown voltages.

II. CALCULATION OF ELECTRIC STRENGTH

(a) *Diagrams.* For drawing the time-voltage curves, sufficient tests shall be made to enable fair curves to be drawn over the time range under investigation.

In order that some idea may be formed of the uniformity of the material, all the experimental values are to be indicated, and when considerable variation is found this fact should be specially mentioned.

As the temperature-voltage curves are taken from the mean curves drawn through the values obtained on the time-voltage tests, the experimental points cannot be indicated on these or on the thickness-voltage curve.

(b) *Measurement of Thickness.* The thickness of the dielectric shall be measured by means of a micrometer or other suitable method.

12. TEST EQUIPMENT FOR POWER FREQUENCY TESTS

(a) *Output of Testing Set.* The output of the testing set shall be sufficient to maintain on the sample under test the necessary voltage for the maximum period required.

(b) *Frequency.* The frequency of the supply voltage shall be approximately 50 cycles, and, if different, its value shall be recorded.

(c) *Application and Regulation of Voltage.* It is essential that the voltage be applied without shock, and in some tests, such as time-voltage tests, that the required voltage should be reached as rapidly as possible.

Methods which could be used for this purpose are given below, and their relative suitability indicated.

(i) *Separate Alternator.* Undoubtedly the best method is to have a separate alternator for the testing transformer. When this is feasible, the H.T. voltage should be controlled by means of a resistance in series with the alternator field. In cases where rapid application of a definite voltage is desired, the field rheostat should be adjusted to give the required voltage before the specimen is inserted, and after inserting the specimen the voltage should be applied by closing a switch in series with the alternator field, or by short circuiting an additional resistance temporarily added.

The generator supply must be disconnected from the testing transformer before the specimen is inserted.

(ii) *Induction Regulator.* The use of an induction regulator designed to enable the voltage to be increased smoothly is the best method to employ when a separate alternator is not available. When a rapid application of a definite voltage is desired, a stop may be fixed at the required point on the regulator and the voltage applied by turning the handle rapidly from zero position to the stop.

(iii) *Tapped Transformer.* This method does not permit the voltage to be increased smoothly and is not recommended when either method (i) or (ii) above is available. If used, the voltage between the stops should be as small as possible. This may be obtained by employing

an auxiliary regulating transformer connected in series with the main regulating transformer, and having a voltage between taps of, say, $1/10$ the voltage between the taps of the main regulating transformer.

When a rapid application of a definite voltage is desired, the regulator should be set to the required position and the voltage applied by closing the primary circuit through a suitable resistance, arrangements being made to short circuit the latter a fraction of a second later. The use of a three-pole switch in which one jaw is arranged to make contact

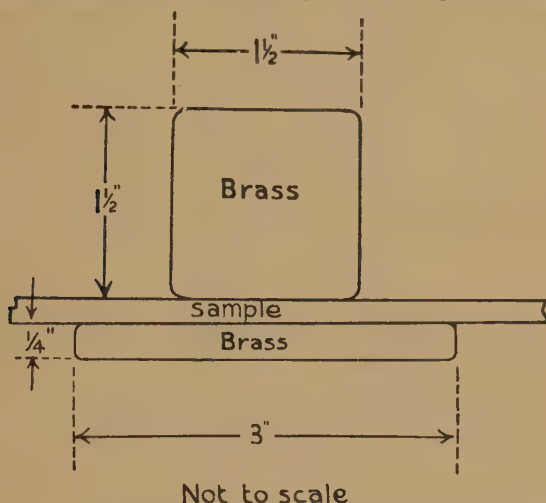


FIG. 4.—Electrodes for Sheet Material.

slightly later than the others is a convenient way to obtain the above result.

(iv) *Series Resistance.* An inductive or a non-inductive resistance could be inserted in series with the primary of the testing transformer. This method, although sometimes the most convenient, is not recommended, as it is liable to distort the wave shape.

If its use is unavoidable and a rapid application of the voltage is required, the same procedure as recommended in (iii) above could be used.

(d) *Wave Shape.* The wave shape shall be as near sinusoidal as possible. If the wave shape is not known to be satisfactory, the peak value shall be ascertained, whilst a specimen is under test and near the point of breakdown, by means of a suitable spark-gap¹ or other method, and the equivalent R.M.S. value taken as 0.707 of the peak value.

(e) *Measurement of Voltage.*² The voltage shall preferably be

¹ For information on suitable spark-gaps and method of use, see Appendix V.

² It should be noted that the directions given in these clauses are not suitable for tests on finished machines. See fourth paragraph in Preface, E.R.A., Ref. L/S2.

measured on the H.T. side of the testing transformer by means of a crest voltmeter, or an electro-static voltmeter. If it is desired to employ an electro-magnetic voltmeter, the instrument should derive its voltage from the H.T. circuit, either directly or through an auxiliary voltmeter transformer. If a special winding in the transformer is used to supply the voltmeter, it shall first be calibrated, when a specimen is under test and on the point of breakdown, by means of one of the other methods indicated.

(f) *Prevention of H.F. Oscillation.*¹ The conditions of the test must be such as to prevent any H.F. oscillations. Precautions must be taken to prevent the occurrence of spark discharges in the circuit in which the specimen is being tested. When a spark gap is used to measure the voltage a non-inductive resistance of about 1 ohm per volt of test pressure shall be inserted in series with the unearthed sphere. This resistance shall not be in series with the specimen under test.

A water tube is the most suitable form of resistance.

13. ELECTRODES

(a) *For Samples in the Form of Flat Sheets or Boards.* When the sample is in the form of a flat sheet or a board, the method of test to be employed is specified below—

(i) *Machinable Materials having an Electric Strength Greater than 1,200 Volts per Mil.*² For the determination of the electric strength of high-grade ebonite and like materials, convenience and economy necessitate that the thickness of the specimen shall not be greater than 20 to 40 mils. The use of disc electrodes is therefore not practicable, and it is recommended that the electrodes employed shall consist of a disc and a 1 in. diameter³ sphere, arranged as shown in Fig. 5. A roughing tool and a finishing tool which have been found suitable for machining the recess of the 1 in. diameter sphere are shown in Fig. 6. When it is required to ascertain the electric strength of the interior of the sheet, the surface must be machined from the flat side of the test specimen. When it is desired to test a specimen with moulded surfaces, proceed as in Section (b) below.

(ii) *Materials having an Electric Strength Less than 1,200 Volts per Mil.* The bottom electrode shall consist of a flat⁴ disc of brass 3 in. diameter by $\frac{1}{4}$ in. thick.

¹ It should be noted that the directions given in these clauses are not suitable for tests on finished machines. See fourth paragraph in Preface, E.R.A., Ref. L/S2.

² 50 kV per mm.

³ In E.R.A. Report Ref. B/Sr, the use of a recess with a diameter of 50 mm. was recommended. This has now been modified to 1 in. diameter, so that it may be machined in a drilling machine.

⁴ When the surface of the specimen is irregular or any difficulty is experienced in obtaining good contact, it is recommended that tinfoil should be interposed between the electrode specified and the dielectric.

The top electrode of a solid cylinder of brass $1\frac{1}{2}$ in. diameter by $1\frac{1}{2}$ in. high.

The sharp edges shall be removed from the electrodes, but the radius at the edge must not exceed $1/32$ in. (Fig. 4).

When it is desired to make electric strength tests in air at temperatures differing from room temperature, the bottom electrode shall consist of a brass block 3 in. diameter by 1 in. thick. (See Clause 5.)

(b) *For Compositions Moulded to Finished Shapes.* When the sample is in the form of a moulded piece, the method of test to be employed is specified below—

(i) *Materials having an Electric Strength Greater than 1,200 Volts per Mil.*¹ The specimen should be moulded to the shape shown in Fig. 5,

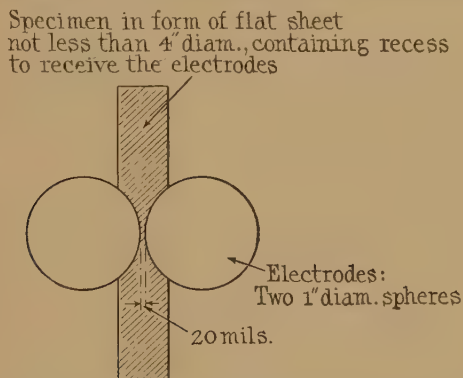


FIG. 5.—Electrodes to be Used with Machinable or Mouldable Materials having an Electric Strength Greater than 1,200 Volts per Mil.

and its electric strength determined with electrodes consisting of a disc and a 1 in. diameter sphere. When it is required to ascertain the electric strength of the interior portions of the specimen, the surface portions must be removed by machining both the flat side and also the spherical recess. The finishing tool shown in Fig. 6 may be employed for the latter.

(ii) *Materials having an Electric Strength Less than 1,200 Volts per Mil.*¹ The use of specimens moulded to a special shape is not recommended for materials having an electric strength less than 1,200 volts per mil,¹ for the following reasons—

Recent researches have definitely shown that in comparing one material with another the results obtained with different shapes of electrodes may vary over a very wide range: in the case of sphere *versus* disc electrodes, sometimes one and sometimes the other giving the higher result. The difference between the values obtained with different shapes of electrodes depends on the conditions of test, the

¹ 50 kV per mm.

moisture content, etc., and it has not been found possible to correlate the values obtained. It is therefore more important than has been

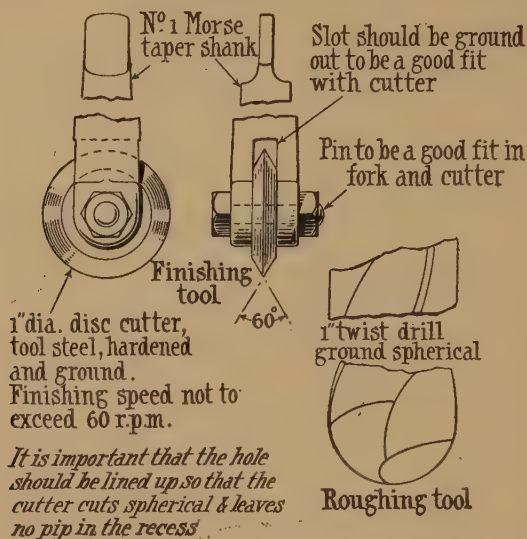


FIG. 6.—Cutter used to Machine Spherical Recess in Specimen in Fig. 5.

realized in the past to employ whenever practicable the same shape of electrode for all classes of solid dielectrics.

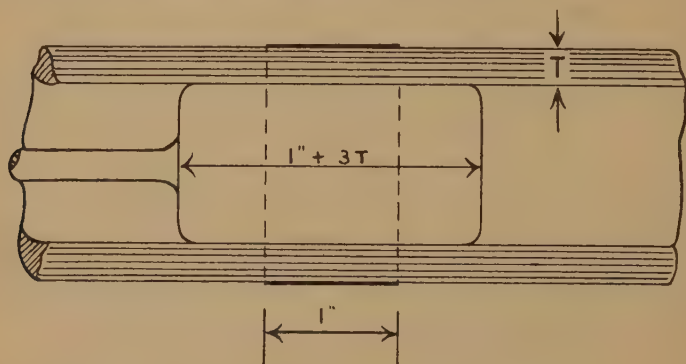


FIG. 7.—Electrodes for Small Tubes.

It is recommended that in future the electric strength of mouldable materials should, whenever practicable, be determined with specimens in the form of flat sheets, thus permitting the use of the disc electrodes shown in Fig. 4.

The question of the shape of electrode which should be employed for the determination of the electric strength of porcelain is still under consideration. Recommendations will be made when the necessary experimental investigations have been completed.

(c) *For Small Tubes (up to about 3 in. Inside Diameter).* The outside electrode shall consist of a band of sheet metal 1 in. wide.

The inside electrode shall consist of a cylinder with the ends rounded to a radius of $\frac{1}{8}$ in., or when a cylinder with rounded ends cannot conveniently be obtained, a sheet metal¹ cylinder sprung into place may be employed. The length of the inside electrode shall not be less than 1 in. plus three times the thickness of the wall of the tube. (See Fig. 7.)

(d) *For Large Tubes (often called Cylinders).* The outside electrode shall consist of a strip of sheet metal² 3 in. wide.

The inside electrode shall consist of a disc $1\frac{1}{2}$ in. diameter of sheet metal sufficiently flexible to conform to the curvature of the cylinder: this disc of sheet metal to be pressed against the inside of the cylinder so as to make good contact over the whole of the area of the disc (Fig. 8).

(e) *For Insulated Bars and Rods.* The conductor on which the insulation is built up shall be employed as the inside electrode.

A strip of metal foil about 3 in. wide and sufficiently flexible to conform to the contour of the coil or bar shall be employed as the outer electrode, as shown in Fig. 9.

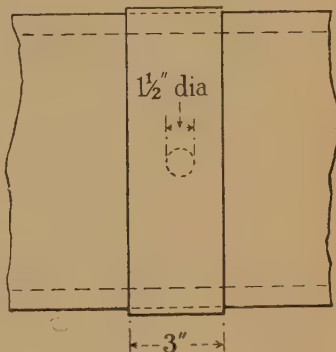


FIG. 8.—Electrodes for Cylinders.

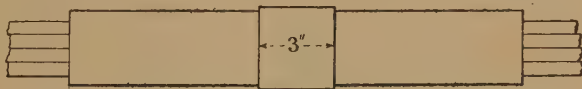


FIG. 9.—Electrode for Insulation Built up on Conductors.

(f) *For Insulated Wires.* When it is required to determine the electric strength of insulated wires the method of test to be employed is specified below—

(i) *Wires of Overall Diameter of 0.040 in. and Less.* A single layer of the wire shall be evenly wound on to a smooth brass tube. The tension on the wire during winding shall be comparable with that

¹ Sheet zinc about $\frac{1}{8}$ in. thick has been found convenient for springing into tubes for forming the inside electrode.

² Soft aluminium foil from 2 to 5 mils thick has been found convenient for use as the outside electrode on tubes.

usually employed in winding coils with wire of the size under investigation. The outside diameter of the brass tube shall be 1 in. for wires of 0.040 in. to 0.020 in. overall diameter, and $\frac{1}{4}$ in. diameter for wire of overall diameter less than 0.020 in. The electric strength of the covering shall be determined by testing from the winding to the brass tube.

(ii) *Wires of Overall Diameter Greater than 0.040 in. and all Sizes of Square or Rectangular Wires.* When the conductor is circular in section, seven straight pieces shall be cut 9 in. long. Six of the lengths shall be arranged symmetrically round the seventh as core and shall be taped tightly together with one half-lapped layer of cotton tape 0.007 in. thick, for a distance of 6 in., as shown in Fig. 10.

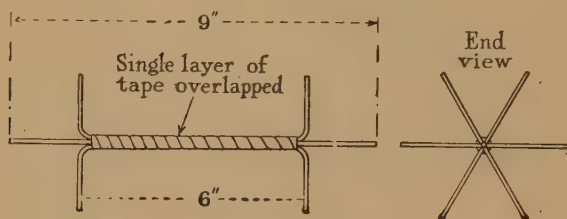


FIG. 10.—Method for Large Sizes of Round Insulated Wire.

When the conductor is square or rectangular in section, seven straight wires each 9 in. long shall be laid together, as shown in Fig. 11, and taped together for a distance of 6 in. as directed above.

Previous to conditioning the ends of the wires shall be bent outwards, as shown in the end view in Figs. 10 and 11. The test shall be made between adjacent wires, and the electric strength of the insulation shall

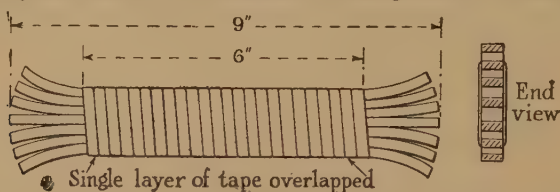


FIG. 11.—Method for Square and Rectangular Insulated Wire.

be taken as half the average value obtained by the above test, and expressed as the electric strength of one side of one wire.

(g) *Compounds Normally Solid at Room Temperature but Liquid when Hot.* Methods of test for bitumens, waxes, filling compounds, etc., are under investigation, recommendations are not yet available.

General Note on the Mechanical Pressure to be Exerted by the Electrodes on the Specimen. When employed under service conditions the insulation may be required to withstand considerable mechanical pressure

at the same time as it is subjected to electrical stress. Also it has been found that in the case of certain classes of dielectrics, the internal heating caused by the leakage currents may volatilize certain constituents of the dielectric and thereby cause the material to swell. As any swelling of the material between the electrodes is liable to result in an increase in the breakdown voltage, it is essential that the mechanical pressure on the electrodes should be sufficient to counteract any such tendency. When considered necessary, suitable¹ mechanical pressure shall be applied by means of deadweights, springs, screws, etc., to prevent any change in distance between the electrodes.

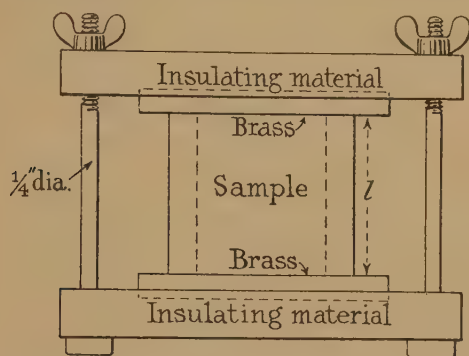


FIG. 12.—Arrangement of Specimen for Longitudinal Breakdown Test.

14. BREAKDOWN ALONG LAMINAE

Materials which are composed of a number of superimposed layers generally have a different electric strength in the direction parallel to the laminae from that in the direction at right angles to the laminae. All such material should, therefore, be subjected to a longitudinal breakdown test carried out as follows—

(a) *Tubes.* Cut a complete ring of axial length l and clamp "hand tight" between flat electrodes, as shown in Fig. 12. The width of material under the electrodes shall be such that the sectional area of the specimen under stress is approximately 1 sq. in. In the case of large tubes three tests shall be made on each ring, the position of the areas tested being 120° apart. Various lengths of specimens shall be tested and a curve plotted showing the relationship between the average electric strength in volts per mil along the laminae and the length of specimen. The range of lengths selected shall be such that the final result, in volts per mil, is approximately independent of the length.

¹ In the case of tests on vulcanized fibre, a pressure of 75 lb. weight on the 1½ in. diameter electrode (Fig. 4) was employed. In general a weight of 50 lb. should be sufficient.

All tests shall be made in oil at 90° C., and the following method employed—

Make a trial breakdown by increasing the voltage from zero to breakdown, as rapidly as the reading on the meter will permit (approximately 5 kV per second has been used). This breakdown is not to be included in the average.

Apply to another specimen of the same length 40 per cent of the breakdown found by the above method, and increase the voltage by 10 per cent steps (i.e. to 50 per cent, 60 per cent, 70 per cent, etc., of the rapidly applied breakdown) at 1 minute intervals till breakdown occurs. At least five determinations on each length shall be used to calculate the average, and the maximum, minimum, and individual values shall also be recorded.

(b) *Sheet Material.* Cut strips of various widths and of any convenient length. Test singly in a manner similar to Tubes (a) above.

15. ELECTRIC STRENGTH OF MATERIALS WHEN SUBJECTED TO LONG APPLICATION OF A.C. STRESS AT POWER FREQUENCIES AND UNDER SERVICE CONDITIONS

Insulating material, when in an electrical machine, has not the same freedom to dissipate heat and moisture, and consequently will not withstand as high a stress as when subjected to an electric strength test as heretofore commonly applied. Such tests give a measure of the relative value of the different materials, but under the working conditions above described the material will not show the high strength so observed. It is, therefore, desirable to determine the maximum stress which the material will withstand when subjected to long application of A.C. stress under such conditions as are comparable with those likely to be experienced in service.

The method for carrying out a sustained voltage test recommended by the Association in its previous Technical Publication Ref. A/S2¹ is at present receiving further consideration with a view to rendering the test more suitable for standardization. The experimental investigations involved are not sufficiently advanced to enable recommendations to be included in the present tentative issue of the directions.

16. TESTS AT RADIO FREQUENCY

Due to the high dielectric loss at high frequencies, the breakdown voltage of insulating materials at radio frequencies is lower than at power frequencies. When a dielectric is overstressed at high frequencies, the heating resulting from the dielectric loss is often of such magnitude as to render the material incapable of functioning as an insulator. Loss of insulating properties at radio frequencies may therefore occur without any evidence of a definite puncture, such as usually occurs when breakdown voltage tests are made at power

¹ In *I.E.E.*, Vol. lx, p. 794, July, 1922.

frequencies. Due to the absence of any sharp point of failure, breakdown voltage tests at high frequencies are of but limited value.

Tests carried out by the American Bureau of Standards¹ have shown that, due to the indefinite nature of radio frequency high-voltage breakdowns, the most satisfactory way at present known of comparing numerically the insulating properties of materials at radio frequencies is by a determination of their power factor and permittivity at radio frequencies. Based on the work of the Bureau of Standards, the American Society for Testing Materials has issued provisional specifications² for high frequency tests. The E.R.A., in one of its researches, is experimenting with the methods suggested by the A.S.T.M., and whilst this research is not complete, certain changes in the methods have been found desirable, and tentative recommendations are given in Appendix VII of the present publication.

PART II

ABRIDGED TESTS ON ELECTRIC STRENGTH

The following methods for the determination of the electric strength of insulating materials are recommended when it is not required to ascertain the characteristics of the material in such detail as provided for in Part I.

17. CONDITIONING

(a) Prior to test the materials shall be exposed to the "Normal" atmosphere as specified in Appendix I.

(b) If it is claimed that the material has special non-absorptive properties, it shall also be tested after exposure to either "damp," "tropical," or "immersed" conditions, as specified in Appendix I.

(c) If it is claimed that the material has special heat-resisting properties, it shall also be tested after exposure to very dry conditions, as specified in Appendix I.

18. METHOD OF EXPRESSING ELECTRIC STRENGTH

The recognized method of expressing the electric strength of materials subjected to these abridged tests shall be the voltage required to produce breakdown in 1 minute when the material is tested at its appropriate temperature, as given in Appendix I. For ease of comparison the volts per mil, followed by a statement of the thickness to which it refers, shall also be given.

19. METHODS FOR OBTAINING THE 1 MINUTE VALUE

To reduce to a minimum the work required to ascertain, with reasonable accuracy, the 1 minute breakdown value, the following method of procedure is recommended—

(a) *Breakdown Through the Thickness of the Material.* Make a trial

¹ See Bureau of Standards Scientific Paper, No. 471.

See A.S.T.M. Publications, D 150-23 T and D 175-23 T.

breakdown by increasing the voltage from zero to breakdown, as rapidly as is consistent with obtaining satisfactory readings of the measuring instrument (approximately 5 kV. per second has been used).

Subject the material to two-thirds the breakdown voltage obtained by the above method and note the time required to produce breakdown.

From the results of this test an approximate idea can be obtained of the voltage which will produce breakdown in about 1 minute; this estimated voltage should then be applied and the time required to produce breakdown noted. From this latter result a still closer approximation can be made. In addition to the trial test, at least five breakdowns should be obtained on each sample, and the values plotted on a time-voltage curve, similar to Fig. 1, but for the time range round 1 minute only. From this curve the voltage required to produce breakdown in 1 minute can be determined.

(b) *Breakdown Along Laminae.* Employ the 1 minute 10 per cent step-by-step method as specified in Clause 14 of Part I of this document. Only one length of specimen shall be tested, the length to be employed for this test depends on the class of material and will be specified in the directions issued for the study of the particular class of material under test.

20. OTHER FACTORS

In conducting the abridged tests for electric strength, the conditions specified for the other factors entering into electric strength tests, such as electrodes, etc., are to be the same as for the research tests dealt with in Part I.

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APPENDIX I

DETAILS OF TEMPERATURE, TIME AND HUMIDITY TO BE USED FOR CONDITIONING THE CLASSES OF DIELECTRICS REFERRED TO, PREVIOUS TO THE DETERMINATION OF THEIR ELECTRIC STRENGTH

Condition.	Class of Dielectric.	Temp. ° C.	Time, hours.	Humidity (relative)* Per Cent.	Sp. Gr. of CaCl_2 † required to give the Stated Humidity at the Stated Temp.
Normal {	B.E.S.A. Class O and A	15-25	18-24	75 †	1.22 at 15° C.
	B.E.S.A. Class B	15-25	18-24	75 †	1.22 at 15° C.
	B.E.S.A. Class C	15-25	18-24	75 †	1.22 at 15° C.
	Unclassified	15-25	18-24	75 †	1.22 at 15° C.
Very dry	—	120-130	18-24	85	—
Dry {	Treated Papers and Fabrics	75-80	2-3	85	—
	Other B.E.S.A. Class O and A Materials	75-80	18-24	85	—
	B.E.S.A. Class B	75-80	18-24	85	—
	B.E.S.A. Class C	75-80	18-24	85	—
Damp {	Unclassified	75-80	18-24	85	—
	B.E.S.A. Class O and A	15-25	18-24	Approximately 95	Water only
	B.E.S.A. Class B	15-25	18-24	Approximately 95	Water only
	Unclassified	15-25	18-24	Approximately 95	Water only
Tropical {	B.E.S.A. Class O and A	45-50 during the day (8 hours, and 15-25 during the night (16 hours)	18-24	Approximately 90 during the day. Saturated during night	Water only
	B.E.S.A. Class B	45-50 during the day (8 hours, and 15-25 during the night (16 hours)	18-24	Approximately 90 during the day. Saturated during night	Water only
Recovered	B.E.S.A. Class O and A	75-80	8-15	85	—
	B.E.S.A. Class C	75-80	8-15	85	—
Chemically Treated {	B.E.S.A. Class C	15-25	168 (1 week)	—	1
	Unclassified	15-25	168 (1 week)	—	—

* For notes on the construction of conditioning chambers and the measurement of humidities therein, see Appendix VI.

† The use of H_2SO_4 is not recommended, as its vapour is liable to be absorbed by the specimen.

‡ This figure is adopted provisionally, awaiting recommendations from another Committee.

§ Air at ordinary room temperature and humidity is to be heated to the temperature specified, without any artificial drying or humidifying.

|| The cubic capacity of the conditioning chamber compared with its internal area and the total area of the specimens must be such that a liberal condensation moisture occurs on the latter during the lower temperature period.

¶ The treatment to be given will depend on the purpose for which the material is required, the following being employed—

- (i) If exposed to rain or water . . . Distilled water.
- (ii) If exposed to sea water . . . 10% solution of salt in distilled water.
- (iii) If exposed to acid . . . Sulphuric acid sp. gr. 1.25 at 15° C.
- (iv) If exposed to alkalis . . . 10% solution of caustic soda.

} Treatment to be given is under consideration.

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APPENDIX II

TABLE I

Periods to be allowed for bringing conditioned specimens to the temperature at which it is required to determine the electric strength when the material is to be tested in air

Class of Dielectric.	Thickness.	Periods for the Temperature differences* indicated, during which the specimen is to be placed between 3 in. $\times$ 1 in. brass discs, previous to the Electric Strength Test in accordance with Clause 13.				
		40° C.	70° C.	100° C.	130° C.	160° C.
B.E.S.A. Class O, A, and B . . .	Not more than $\frac{1}{8}$ in.	1 min.	1 min.	2 min.	2 min.	3 min.
B.E.S.A. Class O, A, and B . . .	> $\frac{1}{8}$ in. but not more than $\frac{1}{4}$ in.	2 min.	3 min.	4 min.	4 min.	5 min.
B.E.S.A. Class O, A, and B . . .	> $\frac{1}{4}$ in. but not more than $\frac{1}{2}$ in.	4 min.	6 min.	8 min.	8 min.	10 min.
B.E.S.A. Class C and unclassified	All thicknesses up to $\frac{1}{2}$ in.	5 min.	5 min.	10 min.	10 min.	10 min.

* This refers to the difference in temperature between the conditioning and testing chambers.

TABLE II

Periods to be allowed for bringing conditioned specimens to the temperature at which it is required to determine the electric strength when the material is to be tested in oil

Class of Dielectric.	Thickness.	Periods for the Temperature differences* indicated, during which the specimen is to be placed between the Electrodes specified in Clause 13 previous to the Electric Strength Test in accordance with Clause 13.				
		40° C.	70° C.	100° C.	130° C.	160° C.
B.E.S.A. Class O, A and B . . .	Not more than $\frac{1}{8}$ in.	1 min.	2 min.	2 min.	3 min.	4 min.
B.E.S.A. Class O, A and B . . .	> $\frac{1}{8}$ in. but not more than $\frac{1}{4}$ in.	2 min.	4 min.	5 min.	6 min.	8 min.
B.E.S.A. Class O, A and B . . .	> $\frac{1}{4}$ in. but not more than $\frac{1}{2}$ in.	5 min.	8 min.	10 min.	12 min.	15 min.
B.E.S.A. Class C and unclassified	All thicknesses up to $\frac{1}{2}$ in.	5 min.	10 min.	15 min.	15 min.	15 min.

Note.—The period to be employed for tests at greater differences of temperature than those referred to above is left to the discretion of the investigator.

* This refers to the difference in temperature between the conditioning and testing chambers.

E.R.A. TECH. PUBL. L/S₂ APPENDIX III

SCHEDULE OF COMMONLY-USED INSULATING MATERIALS AND PARTICULARS OF THE CONDITIONS OF TEST UNDER WHICH THEIR
ELECTRIC STRENGTH SHOULD BE DETERMINED

R. = Research tests as covered by Part I of this document. A. = Abridged tests as covered by Part II of this document.

Material.	Test in Air at ° C.							Test in Oil at ° C.			
	20	60	90	120	150	180	200	250	300	20	60
<i>Class O—</i>											
Untreated Papers	R.	R.	R.A.	R.	—	—	—	—	—	—	—
Untreated Pressboard	R.	R.	R.A.	R.	—	—	—	—	—	—	—
Untreated Cotton	R.	R.	R.A.	R.	—	—	—	—	—	—	—
Untreated Linen	R.	R.	R.A.	R.	—	—	—	—	—	—	—
Untreated Natural and Artificial Silk	R.	R.	R.A.	R.	—	—	—	—	—	—	—
Untreated Soft Woods	R.	R.	R.A.	R.	—	—	—	—	—	—	—
<i>Class A—</i>											
Treated* Papers	R.	R.	R.A.	R.	—	—	—	—	—	R.	R.
Treated* Pressboard	R.	R.	R.A.	R.	—	—	—	—	—	R.	R.
Treated* Cotton, Linen, and Natural or Artificial Silk	R.	R.	R.A.	R.	—	—	—	—	—	R.	R.
Vulcanized Fibre	R.	R.	R.A.	R.	—	—	—	—	—	R.	R.
Varnish paper Products	R.	R.	R.A.	R.	—	—	—	—	—	R.	R.
Untreated Hard Woods	R.	R.	R.A.	R.	—	—	—	—	—	R.	R.
Treated* Soft and Hard Woods	R.	R.	R.A.	R.	—	—	—	—	—	R.	R.
Mica Products containing Less than ... † (by Volume) of Mica	R.	R.	R.A.	R.	—	—	—	—	—	R.	R.
Untreated or Treated Asbestos Pro- ducts containing more than ... † (by Weight) of Ignitable Matter	R.	R.	R.A.	R.	—	—	—	—	—	R.	R.

* Impregnated with insulating material (see British Standard Specification No. 168) or immersed in oil.
† This value is before delamination tests.

SCHEDULE OF COMMONLY-USED INSULATING MATERIALS—(contd.)

Material.	Test in Air at ° C.								Test in Oil at ° C.				
	20	60	90	120	150	180	200	250	300	20	60	90	120
Class B— Untreated and Treated Asbestos Pro- ducts containing Less than . . . * (by Weight) of ignitable matter Mica Products containing More than } . . . * (by Volume) of Mica	R.	—	R.A.†	—	R.A.†	R.	—	—	—	R.	—	R.A.	R.
	R.	—	R.A.†	—	R.A.†	R.	—	—	—	R.	—	R.A.	R.
Class C— Block Mica Porcelain § Glass Marble and Slate Lava and Steatite Natural and Reconstructed Silica	R.	—	R.A.†	—	R.	—	R.A.†	R.	R.	R.	—	R.A.	R.
	R.	—	R.A.†	—	R.	—	—	—	—	R.	—	R.A.	R.
	R.	—	R.A.†	R.	—	—	—	—	—	R.	—	R.A.	R.
	R.	—	R.A.†	—	R.	—	—	—	—	R.	—	R.A.	R.
	R.	—	R.A.†	—	R.	—	R.A.†	R.	R.	R.	—	R.A.	R.
Not yet Classified— Ebonite and Rubber Products Bituminous or Natural Gum Products. Syn. Resin Mouldings Arc-resisting Materials Gums, Waxes, Bitumen, etc.	R.	R.A.	†	—	—	—	—	—	—	R.	R.A.	†	—
	R.	R.	R.A.	†	—	—	—	—	—	R.	R.	R.A.	†
	R.	R.	R.A.	R.	†	—	—	—	—	R.	R.	R.A.	—
	R.	R.	R.A.†	—	R.	—	R.A.†	—	R.	—	—	—	—
	R.	R.	R.A.	—	—	—	—	—	—	—	—	—	—

* This value is being determined by means of experimental investigation; recommendations are not yet available.

† If the material is tested after exposure to "normal," "damp," or "tropical" conditions, the abridged electric strength tests are to be made only at 90° C. and, where applicable, all such 90° C. tests are to be made in oil.

‡ The maximum test temperature and maximum service temperature of moulded compositions will be governed by the grade temperature of the material determined from either mechanical or electrical considerations. Certain of these materials will be found to fall within the O, A, B, C classification, if their grade temperature is determined by an appropriate test.

§ The question of the temperatures and electrodes to be employed for the determination of the electric strength of porcelain is under investigation.

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APPENDIX IV

METHOD OF CALCULATING THE ELECTRIC STRENGTH FROM THE MAXIMUM VOLTAGE GRADIENT ON THE DIELECTRIC

(a) WHEN CONCENTRIC CYLINDRICAL ELECTRODES ARE EMPLOYED

IF a homogeneous dielectric is tested in the form of a tube between concentric cylindrical electrodes, the distribution of the electric stress throughout the thickness of the dielectric will be a logarithmic function of the thickness and will be greatest on the layer adjacent to the inner electrode.

TABLE A
Variation of Maximum Stress to Mean Stress for Various Values of "a"

$a = \frac{\text{Outside diameter}}{\text{Inside diameter}}$	Maximum Stress.
3	1.82 × Mean stress
2	1.44 × Mean stress
1.5	1.23 × Mean stress
1.4	1.20 × Mean stress
1.3	1.15 × Mean stress
1.2	1.10 × Mean stress
1.1	1.045 × Mean stress
1.05	1.020 × Mean stress

Let V = the breakdown voltage

R = the radius of the outside of the tube

r = the radius of the inside of the tube

and $a = \frac{R}{r}$ or $\frac{\text{outside diameter of tube}}{\text{inside diameter of tube}}$

Then the maximum stress on the dielectric

$$= \frac{V}{r \log_e a}$$

and the mean stress

$$= \frac{V}{r(a-1)}$$

The relationship between the maximum stress and the mean stress for various values of (a) is given in Table A.

The above values for the maximum stress are only true when there is a logarithmic distribution of electric stress throughout the thickness of the tube. For various reasons it is frequently impracticable to predetermine the true electric strength by calculations on the basis of the maximum stress which would be given by the above formula.

(b) WHEN THE ELECTRODES CONSIST OF A 1 INCH DIAMETER
EMBEDDED SPHERE AND A FLAT PLATE

In the case of a homogeneous dielectric, the relationship between the maximum stress and the mean stress is given in Table B for various thicknesses of dielectric.

TABLE B
*Variation of Maximum Stress to Mean Stress for
Various Thicknesses of Dielectric*

Minimum Thickness of Specimen.	Maximum Stress.
Mils.	
20	1.03 × Mean stress
40	1.06 × Mean stress
80	1.11 × Mean stress
120	1.17 × Mean stress
160	1.22 × Mean stress
200	1.28 × Mean stress

As mentioned in the last paragraph of Section (a) above, the values given for the maximum stress do not always apply.

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APPENDIX V

MEASUREMENT OF VOLTAGE WITH SPARK-GAPS

(a) GENERAL

IF proper precautions are taken, a spark-gap may be used for the determination of the peak value of the voltage wave, and also for checking and calibrating voltmeters for H.V. tests.

Most of the recommendations contained in this Appendix are based on methods recommended in the Standards of the American Institute of Electrical Engineers.

(b) RANGE OF VOLTAGE

For the above purposes a suitable sphere-gap shall be used for voltages above 50 kV. and is preferable down to 30 kV. A needle spark-gap may be used for voltages from 10 kV. to 50 kV.

(c) NEEDLE SPARK-GAP

The needle spark-gap shall be between new sewing needles, supported axially at the ends of linear conductors, which are at least twice the length of the gap. There must be a clear space around the gap for a radius at least twice the gap length.

In the Standards of the American Institute of Electrical Engineers it is stated that the values given in Table A refer to No. 00 double long needles. As needles are not standardized, any specified size is liable to slight variation in gauge, taper, and diameter of point. The nearest English needle to the one specified by the A.I.E.E. is No. 17 double long, and this size may be satisfactorily used for the needle spark-gap values given in Table A and Fig. 13.

TABLE A

*Needle-gap Spark-over Voltages (at 25° C. and 760 mm. barometer
and 80 per cent Relative Humidity)*

R.M.S. Kilovolts.	Sparking Distance, mm.	R.M.S. Kilovolts.	Sparking Distance, mm.
10	11.9	35	51
15	18.4	40	62
20	25.4	45	75
25	33	50	90
30	41	—	—

For accurate work it is recommended that a fresh needle be employed for each test, although there is evidence that slight burning of the points is negligible, provided the distance be adjusted to compensate. This feature is the subject of further research.

The sparking distance in air between No. 17 double long sewing needle points for various root-mean-square sinusoidal voltages shall be assumed to be as shown in Table A and Fig. 13.

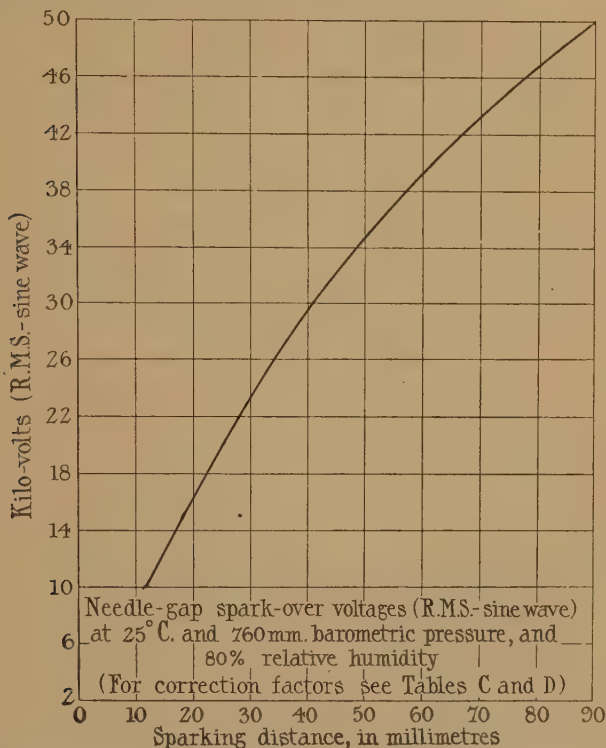


FIG. 13.—Spark-over Voltages (R.M.S. Sine Wave) for Needle-gap at 25°C. 760 mm. barometric pressure, and 80 per cent relative humidity.

(d) SPHERE SPARK-GAP

The standard sphere spark-gap shall be between two suitably mounted spheres. No extraneous body, or external part of the circuit, shall be nearer the spheres than twice their diameter.

The shanks shall not be greater in diameter than one-fifth the sphere diameter. Metal collars, etc., through which the shanks extend, shall be as small as practicable, and shall not, during any measurement, come closer to the sphere than the maximum gap length used in the measurement.

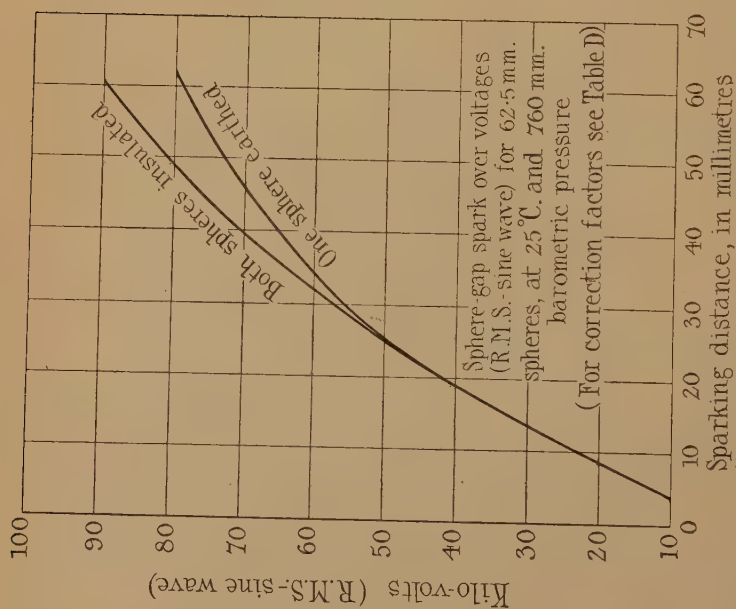


FIG. 14.—Spark-over Voltages (R.M.S. Sine Wave) for 62.5 mm. Diameter Spheres at 25° C. and 760 mm. Barometric Pressure.

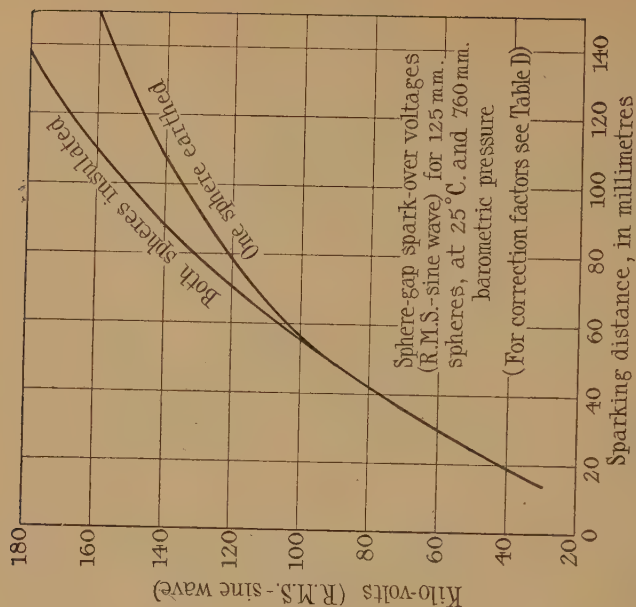


FIG. 15.—Spark-over Voltages (R.M.S. Sine Wave) for 125 mm. Diameter Spheres at 25° C. and 760 mm. Barometric Pressure.

The apparatus shall be set up for use in a space comparatively free from external dielectric fields. Care should be taken that conducting bodies forming part of the circuit, or at circuit potential, are not so located with reference to the gap that their dielectric fields are superposed on the gap, e.g. the protecting resistance should not be arranged

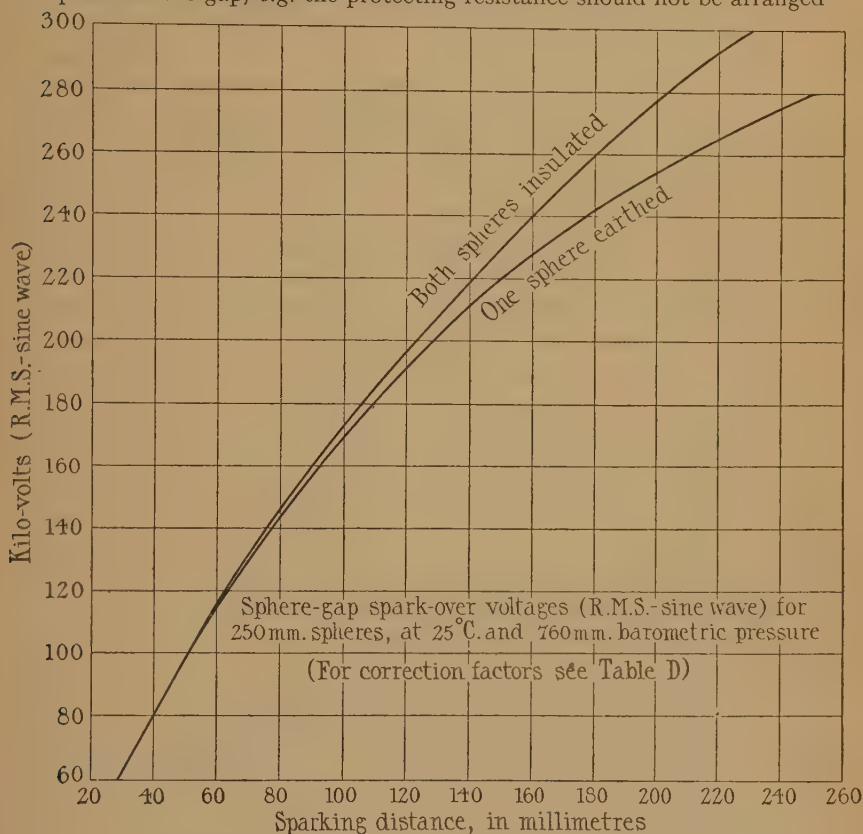


FIG. 16.—Spark-over Voltages (R.M.S. Sine Wave) for 250 mm. Diameter Spheres at 25° C. and 760 mm. Barometric Pressure.

so as to present large masses or surfaces near the gap, even at a distance of two sphere diameters.

In case the sphere is grounded, the spark point of the grounded sphere should be approximately five diameters above the floor or ground.

The spheres shall be as truly spherical as possible.

The sparking distance between spheres for various R.M.S. sinusoidal voltages shall be assumed to be as shown in Table B and in Figs. 14 to 17 inclusive.

TABLE B
Sphere-gap Spark-over Voltages (at 25° C. and 760 mm. barometric pressure).

Kilovolts.	Sparking Distance in Millimetres							
	62.5 mm. Spheres.		125 mm. Spheres.		250 mm. Spheres.		500 mm. Spheres.	
	One Sphere Earthed.	Both Spheres Insulated.	One Sphere Earthed.	Both Spheres Insulated.	One Sphere Earthed.	Both Spheres Insulated.	One Sphere Earthed.	Both Spheres Insulated.
10	4.2	4.2	—	—	—	—	—	—
20	8.6	8.6	—	—	—	—	—	—
30	14.1	14.1	14.1	—	—	—	—	—
40	19.2	19.2	19.1	14.1	—	—	—	—
50	25.5	25.0	24.4	19.1	—	—	—	—
60	34.5	32.0	30	24.4	—	—	—	—
70	46.0	39.5	36.0	30.0	29	—	—	—
80	62.0	49.0	42.0	36.0	35	29	—	—
90	—	60.5	49.0	42.0	41	35	—	—
100	—	—	56.0	49.0	46	45	41	41
120	—	—	79.7	55.0	52	45	46	45
140	—	—	108.0	71.0	64	51	52	51
160	—	—	150.0	88.0	78	63	63	62
180	—	—	—	110.0	92	77	74	73
200	—	—	—	138.0	109	90	85	83
220	—	—	—	—	128	106	97	95
240	—	—	—	—	150	123	108	106
260	—	—	—	—	177	141	120	117
280	—	—	—	—	210	160	133	130
300	—	—	—	—	250	180	148	144
320	—	—	—	—	250	203	163	158
340	—	—	—	—	250	231	177	171
360	—	—	—	—	—	265	194	187
380	—	—	—	—	—	—	214	204
400	—	—	—	—	—	—	234	221
					—	—	255	239
					—	—	276	257

NOTE.—The sphere-gap is more sensitive than the needle-gap to momentary rise of voltage, and the voltage required to spark over the gap should be obtained by slowly closing the gap under constant voltage, or by slowly raising the voltage with a fixed setting of the gap. Open arcs should not be permitted in proximity to the gap during its operation, as they may affect its calibration.

(e) FACTORS INFLUENCING SPARK-OVER VOLTAGE

The spark-over voltage of an air-gap is influenced by the following—

(i) *Humidity*. The voltage required to spark across a needle-gap is influenced by the relative humidity of the air.

The values in Table A refer to a relative humidity of 80 per cent. Provided a needle-gap is not used above 30 kV, variations in relative

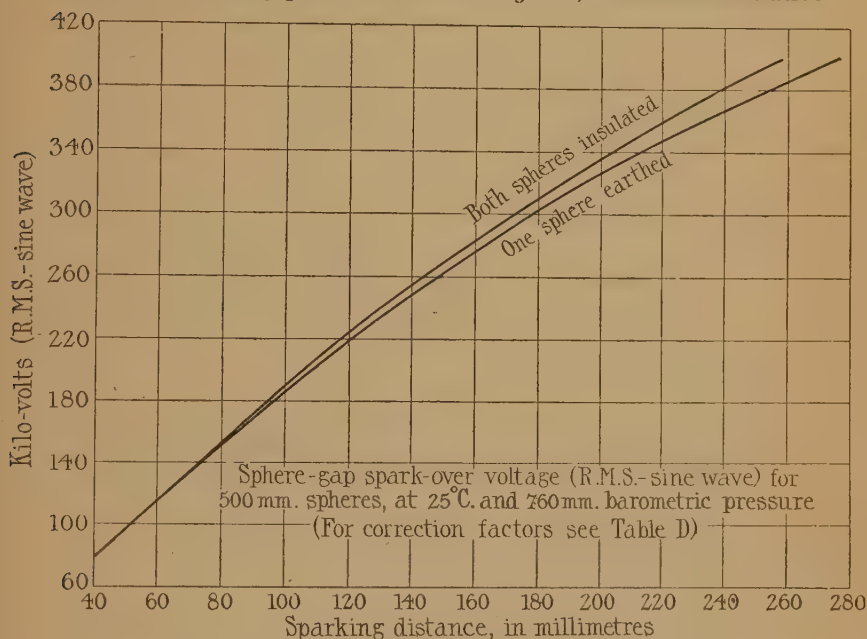


FIG. 17.—Spark-over Voltages (R.M.S. Sine Wave) for 500 mm. Diameter Spheres at 25° C. and 760 mm. Barometric Pressure.

humidity will not affect the spark-over voltage. At higher voltages the spark-over voltage for a given gap setting decreases with decrease in relative humidity.

The magnitude of the effect of change in humidity is shown in Table C and Fig. 18. This curve gives the approximate correction factor and holds for the range from about 85 per cent to 55 per cent relative humidity.

From Fig. 18 it will be seen that the effect of each 1 per cent change in relative humidity increases with the spark-over voltage, and for this reason needle-gaps are not as accurate as sphere-gaps for voltages above about 30 kV.

Provided a sphere-gap is set so that corona does not form before spark-over occurs, the spark-over voltage of a sphere-gap is independent of humidity.

(ii) *Air Density.* The distance through which a given voltage will cause a spark to pass through air depends on the density of the air.

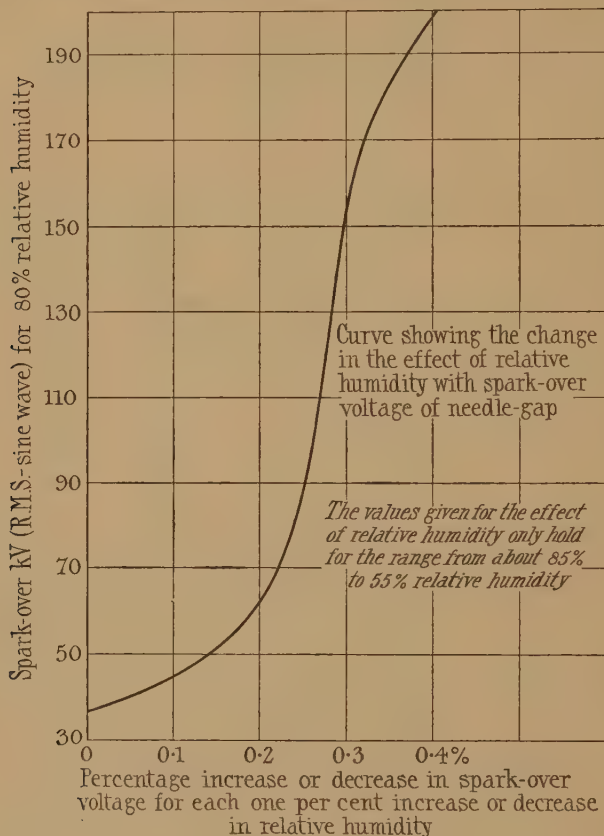


FIG. 18.—Humidity Effect on Spark-over Voltage.

The spark-over voltage for a given gap thus decreases with decreasing barometric pressure and increasing temperature. This variation may be considerable at high altitudes. When the variation from sea-level is not great, the relative air density may be used as the correction factor ; when the variation is great, or greater accuracy is desired, the correction factor corresponding to the relative air density should be taken from Table D, in which

$$\text{Relative air density} = \frac{0.392 b}{273 + t}$$

b = barometric pressure in mm.

t = temperature in °C.

TABLE C

Variation of Spark-over Voltage of Needle-gap with Relative Humidity

Spark-over voltage for 82.5 per cent relative humidity as given by Peek. ¹	Approximate reduction in spark-over voltage at 57 per cent relative humidity. Calculated from Peek's 82.5 per cent and 57 per cent relative humidity curves. ¹		Approximate percentage increase or decrease in spark-over voltage for each 1 per cent increase or decrease in relative humidity calculated from the spark-over voltage at 80 per cent relative humidity.
	kV.	Per cent.	
35	0	0	0
50	1.8	3.6	0.14
60	3	5.0	0.20
70	4	5.7	0.22
80	5	6.2	0.24
100	6.7	6.7	0.26
120	8.5	7.1	0.28
140	10.5	7.5	0.30
160	13	8.1	0.31
170	14	8.2	0.32
180	16	8.9	0.35
200	20	10.0	0.40

¹ See *Dielectric Phenomena in High Voltage Engineering*, by F. W. Peek, junr. First Edition, p. 87.

TABLE D

Air Density Correction Factors for Sphere-gaps

Relative Air Density.	Diameter of Standard Spheres in mm.			
	62.5	125	250	500
0.50	0.547	0.535	0.527	0.519
0.55	0.594	0.583	0.575	0.567
0.60	0.640	0.630	0.623	0.615
0.65	0.686	0.677	0.670	0.663
0.70	0.732	0.724	0.718	0.711
0.75	0.777	0.771	0.766	0.759
0.80	0.821	0.816	0.812	0.807
0.85	0.866	0.862	0.859	0.855
0.90	0.910	0.908	0.906	0.904
0.95	0.956	0.955	0.954	0.952
1.00	1.000	1.000	1.000	1.000
1.05	1.044	1.045	1.046	1.048
1.10	1.090	1.092	1.094	1.096

Corrected curves may be plotted for any given altitude, if desired. It will be noted in Table D that for values of relative air density above 0.9 the correction factor does not differ greatly from the relative air density.

The spacing at which it is necessary to set a gap to spark-over at some required voltage is found as follows: Divide the required voltage by the correction factor given in Table D and use the new voltage thus obtained to find the corresponding spacing from Table B, using a graph of the latter if more convenient.

(iii) *Other Factors.* As an indication of the effect of other factors, the following results (see Table E), reported by F. W. Peek,¹ are given for the guidance of those using spark-gaps for the measurement of high voltages.

TABLE E

Spark-over Voltage of 12.5 cm. Spheres under the Conditions Stated

Condition of Sphere.	Per cent of Normal Spark-over Voltage.	
	5-cm. Gap.	10-cm. Gap.
Polished	100%	100%
Thin Coating of Dry Dust	98%	98%
Excessive Pitting (craters 0.4 mm. deep and beads 0.25 mm. in height)	90%	75%
Rain 0.2 in. ppt. per min. (polished spheres).	42%	39%

Marvin² has shown that cotton lint from a dry cloth may reduce the spark-over voltage of a 25 cm. diameter sphere-gap set with gap of 123 mm. to 78 per cent of normal value.

It is recommended that previous to use the spheres should be polished and wiped with a wash-leather which is slightly oily.

(f) USE OF RESISTANCE IN SERIES WITH SPARK-GAP

To prevent high frequency oscillations and to limit the current when spark-over occurs, a non-inductive resistance of about 1 ohm per volt of test pressure shall be inserted in series with the spark-gap. If the test is made with one electrode grounded, the resistance shall be inserted directly in series with the non-grounded electrode; if neither terminal is grounded, one-half shall be inserted directly in series with each electrode. In either case the resistance shall be as near the measuring gap as possible, but must be arranged so as to fulfil the condition set forth in (d) above.

¹ See *G.E. Review*, June, 1916, p. 564.

² See *Elec. World*, March 18th, 1916.

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APPENDIX VI

NOTES ON CONDITIONING CHAMBERS AND THEIR EQUIPMENT

(a) CONSTRUCTION

(i) *Cold Chambers.* For conditioning or test chambers which are not required to be heated, a satisfactory and convenient method of construction is to make the chamber of $\frac{3}{4}$ in. tongue and grooved boards and to line the inside with thin sheet metal. The latter should be soldered down all joints, such as those occurring where the sides meet the top and bottom. The use of a sheet metal lining is essential when it is required to employ the chamber for very high or very low humidities.

(ii) *Hot Chambers.* When a chamber is required for temperatures above those of the laboratory, an electrically heated oven having double walls of sheet metal with the interspace suitably packed is recommended.

(b) METHOD FOR OBTAINING THE SPECIFIED HUMIDITIES IN COLD CHAMBERS

(i) *Relative Humidity of Approximately 100 per cent.* Even when a large area of water is freely exposed in a chamber with walls of a non-absorptive material, it is impracticable to obtain a relative humidity exceeding 95 per cent. It has been found, however, that if a constant current of air be made to pass over the surface of the exposed water, and the air in the chamber be kept continually stirred, there is no difficulty in obtaining a relative humidity of 96 to 98 per cent. A simple method which has been used for obtaining this high humidity is shown in Fig. 19. Unless the conditioning chamber is really airtight, the fan must be designed as a stirrer only, any difference in pressure between the air in the chamber and the air in the laboratory results in leakage which renders the attainment of a high humidity very difficult.

(ii) *Normal Condition.* For normal condition a humidity of 75 per cent obtained by the use of CaCl_2 of specific gravity 1.22 at 15° C. is specified. In order that the required humidity may be obtained in all parts of the chamber, especially when the chamber is loaded with specimens, it is essential that the air should be kept continuously circulating over the solution and between and around the specimens. The method shown in Fig. 19 has been found satisfactory.

(c) MEASUREMENT OF HUMIDITY IN COLD CHAMBERS

The wet and dry bulb hygrometer is an unreliable instrument if used in still air, but by ensuring that the velocity of the air past the bulb is of the order of 3 metres per second, it can be converted into an instrument of satisfactory precision. In the chamber shown in Fig. 19, a window is provided in one side, through which the thermometers can be read. This arrangement has been found very convenient.

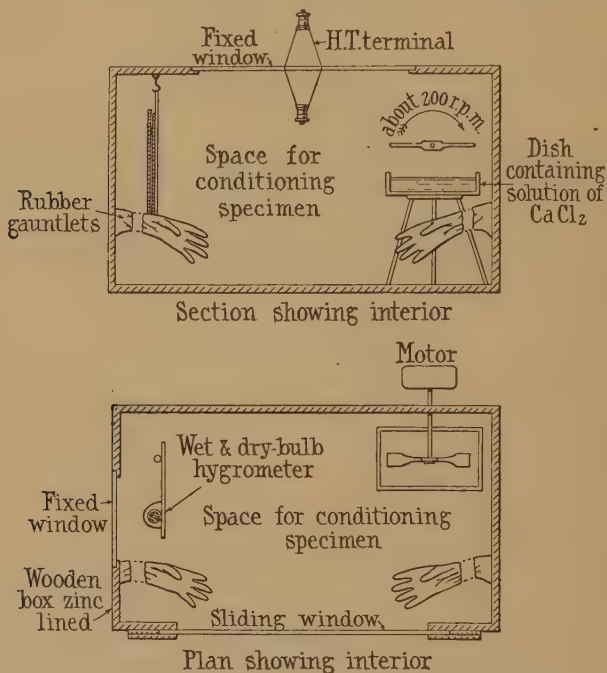


FIG. 19.—Cold Conditioning Chamber and Equipment.

If for any reason an air velocity past the bulbs of at least 3 metres per second cannot be ensured, a dew point hygrometer should be used. The surface on which the deposit occurs should be of well burnished silver, and the usual aspiration method through ether, alcohol, or water can be used for producing the necessary lowering of temperature.

When temperature differences are small, it is important that the fluid be in actual contact with the silver surface if accurate results are required. The temperature gradient through the glass, if a silver thimble is fitted on to a test tube in the usual manner, may be of importance, and the temperature of the fluid will be appreciably lower than that of the silver surface, giving too low a value of the estimated humidity.

(d) METHOD FOR OBTAINING THE SPECIFIED TEMPERATURES
IN HOT CHAMBERS

Electrically-heated ovens should always be employed. With a view to obtaining as uniform a temperature as possible, the heating elements should be distributed over the whole of the bottom of the oven and the temperature regulated by means of an external resistance. To obtain a wider variation of temperature, series parallel connections can be employed, provided all the units are left in circuit. If the specimens and internal fittings are suitably arranged, the convection currents, set up by the heating elements, will be sufficient to keep the temperature and humidity in different parts of the chamber as uniform as is necessary.

(e) TEST CHAMBERS

With many dielectrics considerable change of moisture content may take place in a very short space of time, as the result of change of humidity or of temperature of the surrounding air. The effects produced by the conditioning may therefore be altered if change of moisture content is permitted during the time elapsing from the end of the conditioning period to the determination of the electric strength. When the latter is determined under oil there is less risk of change of moisture content than in the case of tests made in air. When tests are made in air, and when it is likely that change of moisture content may occur, the electrical tests should always be made either in the conditioning chamber or, as is usually found more convenient, in an enclosed chamber specially designed for conducting the electrical tests. The use of rubber gauntlets fastened in the sides of the chamber, as indicated in Fig. 19, permits the investigator to change the connections and manipulate the samples without opening the chamber. The glass window at the top ensures good illumination of the interior, by either daylight or artificial light.

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APPENDIX VII

THE DETERMINATION OF THE ELECTRICAL CHARACTERISTICS OF INSULATING MATERIALS AT HIGH FREQUENCIES

*H.F. Test No. 1. The Determination of the Power Factor and Permittivity
of Electrical Insulating Materials at Radio Frequencies*

(a) GENERAL

THE method of test described is put forward in tentative form in response to requests received for information on H.F. tests. The method described is based on the tentative method suggested by the American Society for Testing Materials in its Serial Designation D 150-23 T.

This method of test, as developed by the E.R.A., is intended to apply to all solid electrical insulating materials.

The behaviour of material under test at radio frequencies is fundamentally different from that at low frequencies.

In this test the power factor of the dielectric is determined at a measured frequency by determining the effective resistance (or equivalent series resistance) and capacity of a condenser made up with the material as the dielectric. The permittivity is calculated from the measured capacity of such a condenser, and the thickness and area of the dielectric.

The dielectric power loss is proportional to the product of the permittivity and the power factor.

(b) GENERATING CIRCUIT

The circuit in which the radio frequency waves are generated is called the generating circuit. The source of radio frequency voltage shall be an electron tube oscillator the frequency of which can be varied over the range desired, and which can be coupled loosely to the measuring circuit. It shall furnish sufficient power so that the presence of the measuring circuit will not reduce its output. The output of the oscillator must be very constant, as any variation in voltage will cause a much larger variation in the final results, because of the differential method used. For this reason it is desirable to have the plate current supplied by a storage battery or other source of very constant power.

The generating circuit must be capable of supplying power at any wave length between 240 metres (1,250 kilocycles per second) and 3,500 metres (86 kilocycles per second).

An arrangement of the generating circuit suggested by the A.S.T.M. is shown in Fig. 20, to which the following particulars apply—

The inductance coil L_g is any one of a series of detachable tubular single layer coils. For the tests outlined it is probable that not more than five will be required. The smaller coil may be made by winding

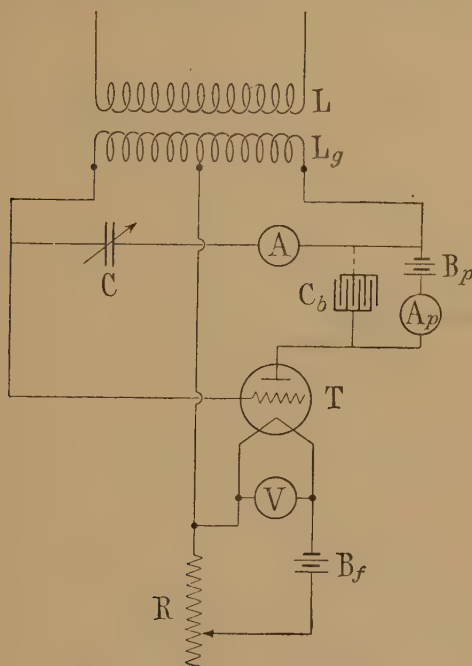


FIG. 20.—Generating Circuit Specified by the A.S.T.M.

13 turns of wire on a $3\frac{1}{2}$ in. tube with 6 turns on either side of the middle clip. The larger coil may be made by winding 112 turns of wire on a $6\frac{3}{4}$ in. tube, 32 turns on either side of the middle clip, and 24 turns outside of both outside clips. The other three coils may be made to cover the gap between these two extremes.

The variable air condenser C may be of any suitable commercial shielded type having a maximum capacity of about 0.003 microfarads (3,000 micro-microfarads). The ammeter A is of the hot-wire type having a range of 0 to 1 ampere. The by-pass condenser C_b may be any type of fixed condenser capable of withstanding 500 volts (direct current).

The plate battery B_p may be a 100 to 300 volt accumulator having an ampere capacity of about 0.2 ampere at an 8 hour discharge rate.

The ammeter A_p may be any type of direct current instrument having a range of 0 to 50 milliamperes. The three-electrode electron tube T may be any of the so-called power tubes rated at 5 watts or over.

	Set No. 1 for Wave Lengths from 230 to 670 Metres.		Set No. 2 for Wave Lengths from 580 to 1,790 Metres.		Set No. 3 for Wave Lengths from 1,380 to 4,480 Metres.	
	Coil marked L_{a1} in Fig. 21.	Coil marked L_{g1} in Fig. 21.	Coil marked L_{a1} in Fig. 21.	Coil marked L_{g1} in Fig. 21.	Coil marked L_{a1} in Fig. 21.	Coil marked L_{g1} in Fig. 21.
Mean diameter (cm.)	10.7	10.7	10.7	10.7	10.7	10.7
Length (cm.)	2.54	1.15	4.65	1.85	8.6	3.7
Number of turns	26	32	82	52	242	104
Diameter of wire (in.)	0.020	0.0124	0.020	0.0124	0.0124	0.0124
Turns per cm.	10.3	28	18	28.2	28.2	28.2
Approximate inductance (microhenries)	100	200	800	460	5,000	1,420

An alternative arrangement of the generating circuit is shown in Fig. 21. During tests made by the E.R.A. it was found that by using two valves, as indicated in Fig. 21, the frequency was much less dependent upon the load taken than it was when a single valve was used.

To cover the required frequency range when employing the circuit shown in Fig. 21, three sets of coils made as indicated below have been found suitable.

For each of the sets coils L_{a1} and L_{g2} were wound on the same tube, each coil being wound in a single layer, leaving about $\frac{1}{8}$ in. between the two coils.

The above mentioned coils are employed in the circuit of the first valve shown in Fig. 21. For the anode coil, L_{a2} , of the second valve, a coil made as follows has been found suitable for the complete range of wave lengths covered by the above—

Mean diameter	= 15.7 cm.
Length	= 4 cm.
Number of turns	= 73
Diameter of wire	= 0.020 in.
Turns per cm.	= 18.2
Approximate inductance	= 1,100 microhenries

(c) MEASURING CIRCUIT

The circuit in which the specimen is placed for test is called the measuring circuit (Fig. 22).

This circuit is composed of—

A condenser employing the test specimen as the dielectric and two metallic surfaces as the conducting plates.

A standard condenser of a suitable design having negligible power factor.

One or more suitable inductance coils with tapings.

A thermo-element of the vacuum type having a resistance of about 8 ohms when the material under test has only moderately good properties, and a lower resistance (say, less than 5 ohms) when the material under test has good properties at high frequencies.

A special double-throw switch equipped with mercury wells (Fig. 23).

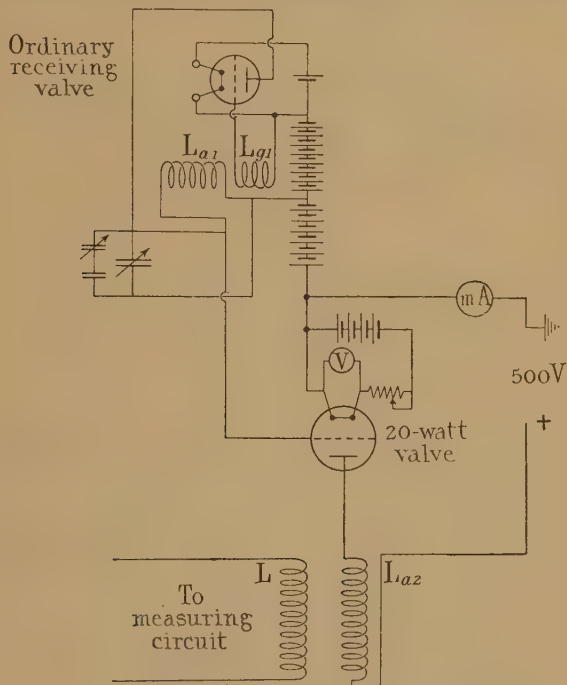


FIG. 21.—Generating Circuit Used by the E.R.A.

A set of resistance links having direct current resistance values ranging from negligible to about 100 ohms (Fig. 24).

A sensitive low-resistance wall galvanometer of the deflecting mirror type or other suitable type of indicating instrument.

The arrangement of the measuring circuit used by the E.R.A. is shown in Fig. 22. This circuit has been found more convenient than the one suggested by the A.S.T.M.

The standard variable air condenser C_s should have a maximum capacity of about 0.001 microfarads (1,000 micro-microfarads). The special switch with mercury wells is shown in Fig. 23. The non-inductive resistance is made as shown in Fig. 24. Several of these resistances are required, but in all cases the distance between the spurs should be the same, because the resistances must fit into the mercury

wells in the switch (Fig. 23). Each of these units has a different value of resistance made so by varying either the length or the diameter of the resistance wire or both.

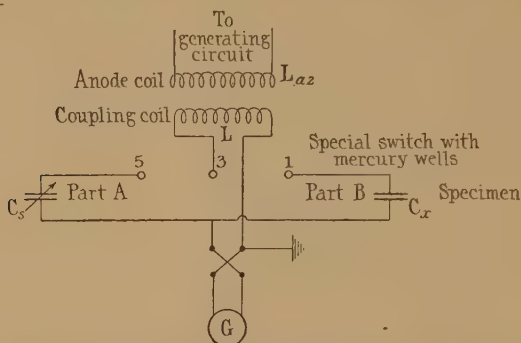


FIG. 22.—Measuring Circuit Used by the E.R.A.

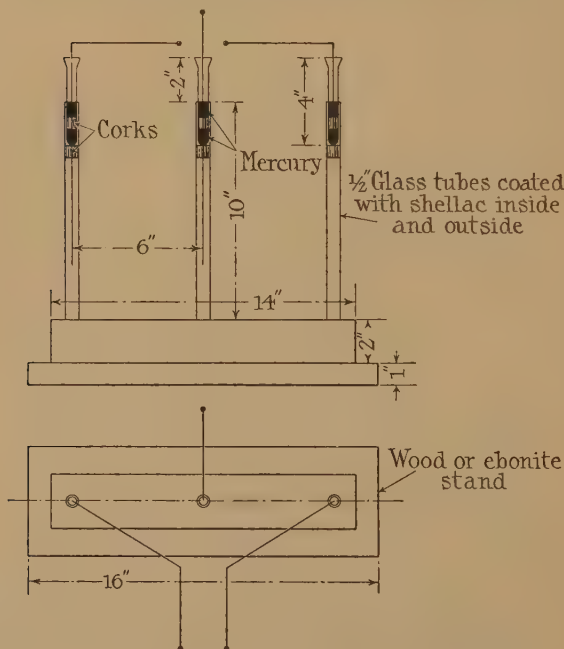


FIG. 23.—Special Switch Used by the E.R.A.

The condenser C_x is made either by floating the test specimen on mercury and pouring mercury on the upper surface until it is filled to a confining barrier or by the use of one of the other methods detailed

in Clause (f). The mercury bath on which the specimen rests is contained in a glass dish which rests on a piece of insulating material, which in turn is supported by a levelling device.

The coil L , Fig. 22, must be designed to have a comparatively low resistance, so that the coil resistance will not be a large proportion of the combined equivalent resistance of the circuit made up of coil L

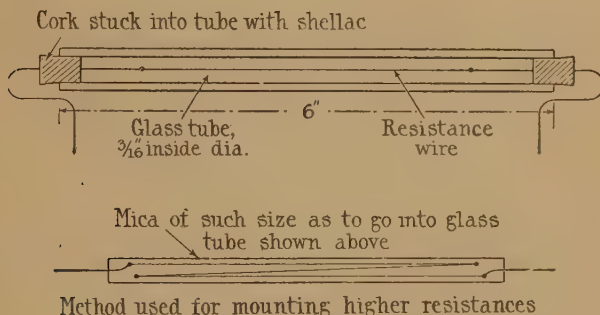


FIG. 24.—Special Non-inductive Resistance.

and the specimen condenser C_x . To cover the frequencies (wave lengths) named, the following coils have been found suitable—

For Wave Lengths from about 1,000 to 4,000 Metres. One single-layer coil wound as indicated below and having seven equidistant tappings has been found convenient.

Mean diameter	= 15.7 cm.
Length	= 20.8 cm.
Number of turns	= 376
Diameter of wire	= 0.020 in.
Turns per cm.	= 18.2

Approximate inductance of complete coil = 11,500 microhenries

For Wave Lengths below 1,000 Metres. Two single-layer coils wound as indicated below and on the same tube, arranged with a space of about 2 cm. between them, have been found suitable.

Mean diameter	= 10.7 cm.
Diameter of wire	= 0.020 in.

Coil 1 consisted of 45 turns and had an inductance of approximately 300 microhenries.

Coil 2 consisted of 15 turns and had an inductance of approximately 50 microhenries.

For further regulation of the inductance, a coil 4 cm. in diameter and wound with 45 turns in 3 layers of 0.018 in. diameter wire, giving an inductance of approximately 100 microhenries, was suspended inside the above coils. The small coil can be conveniently used with the other coils, either as a variometer or as a loading coil.

The thermo-element T is of the crossed-wire vacuum type. The resistance of the thermo-element should be from 3 to 8 ohms.

The galvanometer G is a sensitive wall galvanometer of the deflecting mirror type. One having a resistance of about 30 ohms and a deflection at a distance of 1 metre of about 80 mm. per microampere has been found suitable.

It has been found very important to arrange the circuits quite symmetrically with respect to the coupling coil and the anode coil. Unequal coupling between the coils and points A and B of the measuring circuit, Fig. 22, causes appreciable errors.

(d) CONDITIONING OF SPECIMENS PREVIOUS TO TEST.

The power factor and permittivity of each sample shall be tested after being conditioned as follows—

- (i) Normal conditions as defined in Appendix I.
- (ii) After immersion in distilled water for 48 hours at about 20° C., followed by exposure to normal conditions for 24 hours.
- (iii) After being freely exposed for 24 hours to a dry atmosphere at 90° C.¹

(e) CONDITION OF SPECIMEN DURING TEST

Tests shall be made as indicated below—

- (i) With specimens previously exposed to "normal" condition and whilst exposed to an atmosphere of normal condition.
- (ii) With specimens previously immersed in water as (ii) in Clause (d) above, and whilst exposed to an atmosphere of normal condition.
- (iii) With specimens previously exposed to 90° C. and whilst at 90° C.²

(f) PREPARATION OF TEST CONDENSER

The following methods are suggested for preparing the condenser required for measuring the power factor and the permittivity of the material—

- (i) *For Rigid Materials in the Form of a Sheet.* Either circular or rectangular test specimens may be used, and the specimen shall be of such dimensions that the capacity of the condenser shall not be less than 200 micro-microfarads (200 $\mu\mu\text{f}$). For a thickness of specimen of $\frac{1}{8}$ to $\frac{1}{4}$ in. a specimen of about 12 by 10 in. is usually satisfactory.

The test condenser is made by floating the specimen on mercury and by placing mercury in an enclosure on the top of the specimen. When tests are to be made at low temperatures the enclosure for the mercury may be made by casting a rim of wax on the top surface of the specimen

¹ If the grade temperature of the material is less than 90° C., the conditioning and the tests shall be made at the grade temperature.

² If the grade temperature of the material is less than 90° C., the conditioning and the tests shall be made at the grade temperature.

and situated about 1 cm. from its edges. For tests at high temperatures the mercury may be enclosed by means of an amalgamated metal rim placed on the top surface of the specimen, and of such dimensions as to leave a clear space of 2 cm. from the outer edge of the rim to the edge of the specimen.

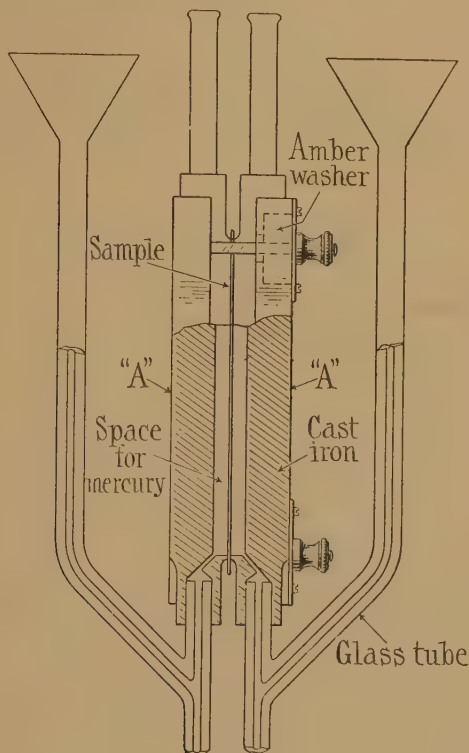


FIG. 25.—Apparatus Used by the E.R.A. for the Measurement of the Power Factor and Permittivity of Flexible Materials.

(ii) *For Materials in the Form of Tubes.* The dimensions of the tube shall be such as to enable a condenser of not less than $200\ \mu\text{mf.}$ being made. One end of the tube shall be plugged with a tight-fitting rubber cork and the condenser made by putting mercury into the tube and placing the tube in a tall glass vessel containing mercury to the required level.

(iii) *For Flexible Materials.* The use of tinfoil as electrodes for flexible materials has been found unsatisfactory. Suitably constructed mercury electrodes have been found to give consistent results. Fig. 25 shows an apparatus which has been found satisfactory for flexible

materials. The apparatus consists of two cast-iron blocks *A*, in which are cut shallow circular recesses to hold the mercury. The rims of these recesses are made only 1 mm. wide and accurately flat, so that when the arrangement is tightened up they form a good fit. Four bolts are fixed into lugs on one of the cast-iron clamps, and passing through holes in corresponding lugs on the other enable the clamp to be tightened by nuts. The insulating between the two points consists of amber washers, through which the bolts pass. The mercury is poured in from below through glass tubes which are cemented into holes bored in the casting, with a cement made from red lead and bakelite. For thin materials, a cast-iron clamp having a mercury space about 3 in. diameter has been found satisfactory.

(g) METHOD OF TEST

The test condenser prepared as stated in (*d*) above shall be arranged in the measuring circuit, as stated in (*c*), and the radio-frequency generator arranged as in (*b*).

The measuring circuit is divided into two parts at the special switch; by connecting wells 1 and 3, the circuit is completed through the specimen, and by connecting wells 3 and 5 the standard air condenser is placed in circuit.

The three wells being unconnected, the generating circuit is switched on, the galvanometer zero adjusted, a link of negligible resistance is inserted between wells 1 and 3, and the resonant frequency obtained by adjustment of the main condenser of the generating circuit, Fig. 21, previously calibrated against a wave-meter. The magnitude of the galvanometer deflection is brought to nearly full scale by bringing the anode coil of the generating circuit nearer to the coupling coil of the measuring circuit. To make sure that an alteration in the position of the anode coil does not affect the zero reading of the galvanometer, the link may be removed from 1 to 3 and the zero checked. The final adjustment of frequency for resonance is, in the case of the circuit shown in Fig. 21, effected by means of the vernier condenser, and the galvanometer deflection then read. The link is next removed from wells 1 and 3, and replaced by a resistance of such a value that the galvanometer deflection is reduced to about half. A slight adjustment of the vernier condenser may be necessary for exact resonance, and, this being done, the deflection is again read; the process is repeated in succession with three or more resistances, of values such that the deflection lies between a third and two-thirds of that which is produced without any added resistance. Then the link is again replaced and the maximum deflection read. This should be the same, to within 0.5 per cent, as that obtained at first.

The procedure detailed above is now repeated with the other part of the circuit, i.e. using wells 3 and 5, the only difference being that the main condenser of the generating circuit is left untouched, resonance being obtained by adjustment of the air condenser of the measuring

circuit. The resistance of this part of the circuit being smaller than that of part *B*, Fig. 22, looser coupling and smaller resistances are required.

(h) CALCULATION OF "EQUIVALENT RESISTANCE" OF SPECIMEN

In this calculation, it is assumed that the condenser with the test specimen as dielectric is equivalent to an air condenser of the same capacity and zero power factor in series with a non-inductive resistance called the "equivalent" or "effective" resistance.

The equivalent resistance of the specimen is calculated as follows—

Referring to Fig. 22—

Let

R_x = the resistance of the specimen C_x .

R_s = the resistance of the standard air condenser C_s .

R_c = the resistance of the remainder of the measuring circuit, including the coupling coil L .

Then

The resistance of Part *B* = $R_x + R_c$, and that of Part *A* = $R_s + R_c$.

As the standard condenser may be considered to have negligible resistance, the resistance of the specimen is that of part *B* minus that of part *A*.

The resistance of parts *A* and *B* is calculated from the experimental values of galvanometer deflection and added resistance as follows—

Let

R_o = the resistance of the circuit with no other resistance inserted.

R_i = the resistance inserted.

D_o = the galvanometer deflection with no other resistance inserted.

D_i = the galvanometer deflection when resistance inserted.

Then

$$R_o = \frac{R_i}{\sqrt{\frac{D_o}{D_i}} - 1}$$

From the values obtained by inserting the three or four resistances, make three or four calculations of the resistance of parts *A* and *B*, take the average value for each part of the circuit, and the difference of these values gives the equivalent resistance of the specimen at the frequency used for the test.

(j) CALCULATION OF POWER FACTOR

Let

R_x = the equivalent resistance of the specimen in ohms.

C_x = the specimen capacity in micro-microfarads.

λ = wave length in metres.

Then

$$\text{Power factor} = 0.188 \frac{R_x \cdot C_x}{\lambda} \text{ per cent (approx.).}$$

The equivalent resistance of the specimen is calculated by the method detailed in (h) above, the specimen capacity is obtained from the reading of the standard air condenser, and the wave length from a wave meter.

(k) CALCULATION OF PERMITTIVITY OF SPECIMEN IN THE
FORM OF SHEET

Let

Cx = the capacity of the specimen in micro-microfarads.

T = average thickness in cm.

S = area of dielectric subjected to electric stress, and expressed in square centimetres.

Then

$$\text{Permittivity} = \frac{Cx \cdot T}{0.0885 \cdot S}$$

(l) DIELECTRIC LOSS

As the energy loss in a dielectric is dependent on both the power factor and also on the permittivity, the best comparison of electrical insulating materials for use at high frequencies is obtained by considering the product of the power factor and permittivity.

(m) ACKNOWLEDGMENTS

As stated in Clause (a), the above method of test is based on the tentative method suggested by the A.S.T.M. in its publication Serial Designation D 150-23 T.

Certain features of the above method are based on uncompleted researches by Mr. D. W. Dye, B.Sc., and Mr. L. Hartshorn, B.Sc., both of the National Physical Laboratory. Certain other features are based on uncompleted researches at City and Guilds Engineering College by Prof. C. L. Fortescue, O.B.E., M.A., and Mr. J. E. P. L. Vigoureux, B.Sc.

*H.F. Test No. 2. Comparison of the Effect on Electrical Insulating
Materials of High Voltages at Radio Frequencies*

(a) GENERAL

Methods of test for comparing the effect on electrical insulating materials of high voltages at radio frequencies are under investigation by the E.R.A. Pending the results of these experimental investigations attention is drawn to the tentative method suggested by the A.S.T.M. in its publication Serial Designation D 175-23 T. With but minor modifications, the above-mentioned A.S.T.M. publication is reproduced below—

(b) EFFECTS OF APPLYING A HIGH VOLTAGE AT RADIO
FREQUENCIES TO INSULATING MATERIALS

This method of test is intended to determine the electric failure and flash-over voltages of electrical insulating materials at radio frequencies.

The failure under radio frequency stress may take the form of charring, buckling, cracking, blistering, softening, or chemical decomposition. Failure through the material is not abrupt, and it therefore requires a certain amount of judgment on the part of the operator to decide just what constitutes failure in any particular case.

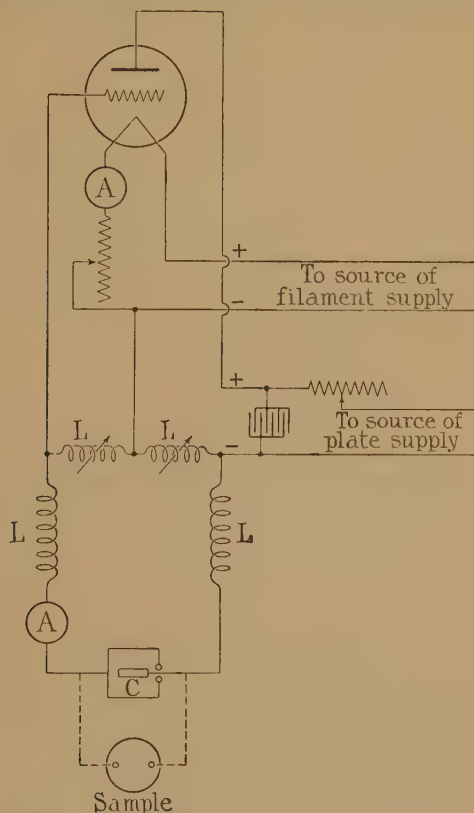


FIG. 26.—Circuit for H.V. H.F. Tests.

When a sheet of insulating material is tested between two metal electrodes passing through it, the heat generated increases with the thickness of the material, while the radiating surface remains nearly constant. Consequently, as the thickness of the sample is increased, the voltage at which failure occurs will decrease. As sufficient data are not available to allow results to be translated from one thickness to another, it is necessary that all comparative tests be made on samples of the same thickness. Hence, in the standard method given below, a definite thickness of sample is specified. This method, of course, is

applicable to other thicknesses of material, but when so used the results should be compared only with similar tests made on like thicknesses of material.

In the flash-over test, heating of the material due to the high frequency current is to be avoided, and it, therefore, is not so important that the samples being compared be of the same thickness. However, as a little heating is unavoidable, it is also desirable in this test to compare samples of the same thickness whenever possible.

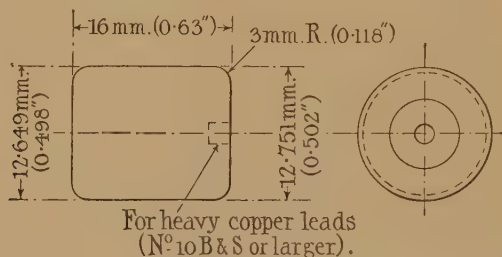


FIG. 27.—Electrodes for Testing Through the Material.

(c) H.V. H.F. GENERATOR

Any type of generator having an output of 500 watts or more and generating continuous waves of 100 and 1,000 kilocycles per second, respectively, and at voltages up to 5,000 or 10,000 volts, depending upon the class of materials tested, is satisfactory. If desired, a circuit similar to that shown in Fig. 26 may be used.

(d) MEASUREMENT OF VOLTAGE

The voltage may be measured by means of the current through a shielded radio frequency ammeter in series with a small shielded air condenser of known capacity across the test terminals or by means of an electrostatic voltmeter designed to withstand radio frequency potentials. Suitable scales shall be provided so that reasonable accuracy will be obtained when measuring any testing voltages up to the maximum desired.

If the ammeter method is used—

$$E \text{ (in volts)} = \frac{16I \times 10^7}{fC}$$

where

I = current in amperes,
 f = frequency in kilocycles per second,
 C = capacity of air condenser in micro-microfarads.

¹ In the formula the value 16 is an approximation, 15.92 being the exact value.

(e) ELECTRODES

The electrodes shall be of brass and shall be clean and polished.

For the dielectric failure test through the specimen, the electrodes shall have the dimensions shown in Fig. 27.

For the flash-over voltage test across the surface of the material, the electrodes shall have the dimension shown in Fig. 28.

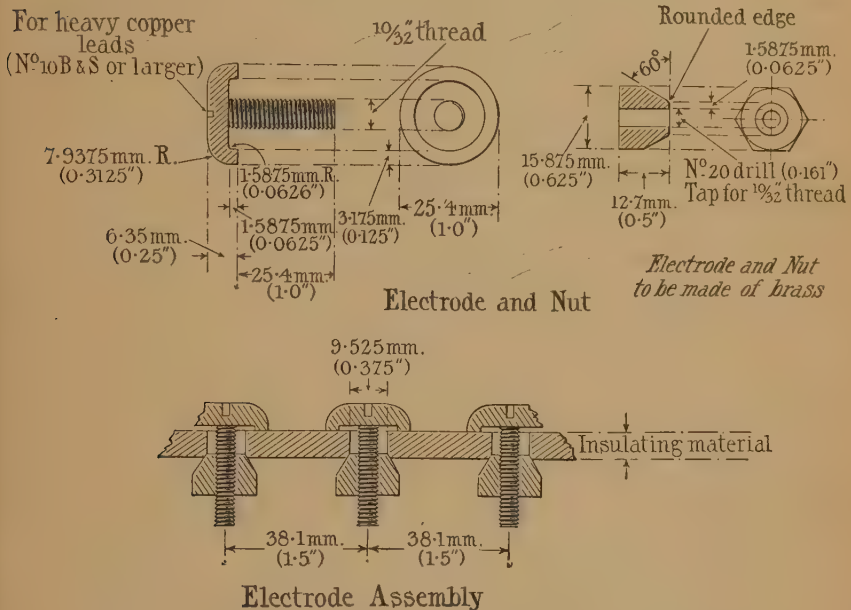


FIG. 28.—Electrodes for Testing Across the Surface of the Material.

(f) TEST SPECIMENS

The specimens shall be representative of the material to be tested, care being taken to select material free from abnormal defects.

For the dielectric failure test, the specimens shall be 6.35 mm. (0.25 in.) in thickness and may be of any convenient size or shape, provided that the centre electrode (see Fig. 29) is at least 57.5 mm. (2.264 in.) from the outside edge at all points. Other thicknesses may be used, but the results therefrom should be used strictly for comparative purposes, as explained under Section (b). If any samples are milled to reduce the thickness, care should be taken not to tear, chip, or otherwise change the character of the material. Four holes, 12.7 mm. (0.5 in.) in diameter, shall be provided in each specimen, one in the centre, and three equally spaced in a circle of 25.4 mm. (1.000 in.) radius, as shown in Fig. 29.

For the flash-over test, the specimens may be any convenient size, the holes being drilled on 38.1 mm. (1.5 in.) centres, as shown in Fig. 28.

(g) CONDITIONING OF SPECIMENS PREVIOUS TO TEST

The effect of H.V. at H.F. shall be determined after specimens prepared in accordance with Fig. 28 have been conditioned as follows—

- (i) Normal condition as defined in Appendix I.¹
- (ii) After immersion in distilled water for 48 hours at about 20° C., followed by exposure to normal condition for 24 hours.

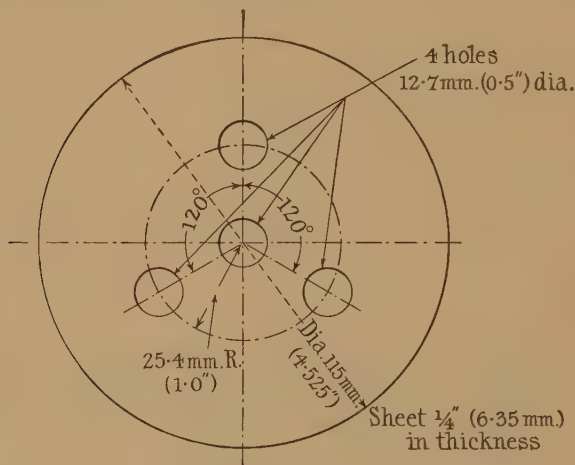


FIG. 29.—Specimen for H.V. H.F. Tests.

(h) CONDITION OF SPECIMEN DURING TEST

During test the specimens shall be exposed to an atmosphere of normal condition, as defined in Appendix I.¹

(j) METHOD OF TEST FOR FAILURE THROUGH THE MATERIAL

One electrode (Fig. 27) shall be inserted in the centre hole in a specimen, and a similar electrode in one of the other three holes. The electrodes must be a tight fit, otherwise corona may form at comparatively low voltage and destroy the material.

The electrodes shall then be connected to the test terminals of the radio-frequency generator. One side of the generator shall be grounded, and this terminal shall be connected to the centre electrode of the specimen. The reason for this is that the failure generally occurs around the high potential terminal, and this will allow the two subsequent tests to be made between the centre and the other two holes, the centre not being destroyed.

¹ Appendix I of L/S2

For materials which ordinarily fail below 3,000 volts, the voltage shall be raised in steps of 500 volts. For materials which ordinarily fail above 3,000 volts, the voltage shall be raised in steps of 1,000 volts. Wherever possible, the initial voltage chosen shall be such that at least three voltage steps will be required to cause failure of the material.

The voltage at each step shall be impressed for 2 minutes, the testing period being counted from the instant when the prescribed voltage is reached, and the time required to reach this voltage not exceeding $\frac{1}{4}$ minute. Whenever samples thicker than that specified are used, this testing period should be changed to 3 minutes.

Tests shall be made between the centre hole and each of the other three holes of each specimen, the specimens being allowed to cool to room temperature after each test.

The average of these three voltages shall be considered as the electric strength of the specimen under the conditions of the tests.

Specimens shall be tested at 100 kilocycles per second (3,000 metres), and also at 1,000 kilocycles per second (300 metres).

(k) METHOD OF TEST FOR FAILURE ACROSS THE SURFACE OF THE MATERIAL

The flash-over tests shall be made under the same conditions and at the same frequencies as specified in (j) above.

The electrodes shall be clamped into position as shown in Fig. 28.

The voltage shall be raised at¹ the rate of about 1,000 volts per second until flash-over occurs. The power shall be removed immediately upon flash-over and the test shall be repeated (without moving the electrodes) until the insulation value has been practically destroyed.

The initial voltage chosen shall be as little below the flash-over voltage as practicable, so that the flash-over will occur as soon as possible without appreciable heating of the material.

The voltage which exists across the specimen when flash-over takes place cannot be determined with the specimen in place, since the voltage would not remain constant until a steady deflection of the measuring instrument was reached and the sample would heat up. Therefore, as soon as discharge occurs, the plate voltage shall be thrown off, all other controls remaining constant, and the test leads removed. The plate voltage then shall be re-applied and the voltage measuring instrument reading taken when a steady deflection is reached.

Tests shall be made in at least three places on each side of each specimen.

¹ The voltage may be increased either by varying the grid and plate inductances or capacities, or by varying the D.C. plate voltage.

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¹ The British Electrical and Allied Industries Research Association.

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